Report No. UT-99.04

I-15 National Test Bed For Advanced Transportation Research And Testing

• Phase 2 Program Report

- Utah Transportation Center
- Utah Department of Transportation
- Federal Highway Administration

BY
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UDOT RESEARCH & DEVELOPMENT REPORT ABSTRACT

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16. Abstract

Phase 2 of a program is detailed that will perform research during the design/build reconstruction of over 16 miles of Interstate 15 in Salt Lake County, Utah. The program is funded through a research grant from the FHWA authorized by TEA-21 legislation specifically targeted to the I-15 National Test Bed Consortium. The program is administered jointly by the Utah Transportation Center, the Utah Department of Transportation and the Federal Highway Administration. Included in the program are technology transfer efforts beyond distribution of the final report.

This program is a follow-on to a Phase 1 research program, a summary of which is also given. In addition, a summary is given of the steps taken to accommodate research in a design/build environment.

Detailed work plans are given for six research studies that are to be performed under this Phase 2 program. These six studies are:

- Push-Over Test of Bridge Bent w/ Advanced Composite Reinforcement, Phase 2;
- Evaluation of Geopier Foundation Systems, Phase 2;
- Lateral Load Field Tests on Pile Groups, Phase 3;
- Field Testing & Computer Modeling of a Curved Steel Girder Bridge, Phase 1;
- Forced Vibration as an NDE Technology, Phase 2; and,
- Existing Column / Beam Evaluation, Phase 1

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INTRODUCTION

A unique research opportunity was created as a result of the Interstate 15 reconstruction in Salt Lake County, Utah. Influenced by the present inadequacies of the system, the Utah Department of Transportation (UDOT) is replacing approximately 16.5 miles of interstate freeway in the Salt Lake Valley over a period of four years. This reconstruction will require more than 5 million cubic yards of fill material and 2.5 million square yards of concrete pavement. In addition, ten urban interchanges will be rebuilt and more than 125 bridges will be replaced. Wasatch Constructors, a consortium with headquarters in Phoenix, Arizona, was chosen as the design/build contractor. The expected completion date for the project is July, 2001, in time for the Winter Olympics that will be hosted by Salt Lake City in 2002.

This section of Interstate 15 was built in the early 1960's, at which time there were about 380,000 residents in the Salt lake metro area. The population has now grown to over one million, which when combined with interstate traffic produces over 600,000 vehicles per day on this part of the corridor. To handle this volume, the corridor will be widened from three to six lanes in each direction, including HOV and auxiliary lanes. Also, over 130 traffic signals on primary and secondary arterials throughout the valley will be integrated into an advanced traffic management system (ATMS) that will be jointly coordinated between three public agencies.

In addition to being functionally deficient, the bridges being replaced are also structurally deficient. Two factors contribute to this deficiency. First, the corridor was built prior to the development of modern seismic design criteria. Salt Lake City is located in a seismically active area. Second, severe weather and winter maintenance activity has resulted in significant deterioration in many areas.

RESEARCH OPPORTUNITY

This unique project presents an opportunity to address vital questions, both regarding the many innovative processes, techniques, designs and materials that are expected to be employed in the new construction, as well as the design capacity and durability of the existing facilities that will be demolished and removed.

Due to the uniqueness of this occurrence, UDOT actively explored various research opportunities. This included the solicitation of research ideas and work plans from anyone interested in participating. A national workshop was held on May 12, 1997, in Salt Lake City to identify and develop a research agenda related to the I-15 Reconstruction Project. Experts from around the country attended and proposed research topics related to bridges, foundations, pavements, materials, construction, maintenance, planning, traffic, safety, and intelligent transportation systems (ITS)

At this forum, both research needs and potential funding sources were identified. Some of the topic areas considered included full-scale testing on existing structures that were being taken out of service. Others included monitoring new materials, processes, construction techniques and methods that were being employed and practiced during the reconstruction project. The proceedings of this workshop may be found in UDOT Report No. UT-97.10.

I-15 NATIONAL TEST BED

In order to achieve the goals of this research agenda a consortium known as the *I-15 National Test Bed for Advanced Transportation Research and Testing* was established. The Utah Department of Transportation (UDOT) entered into a Memorandum of Understanding with the three major universities in Utah having civil engineering research programs, Brigham Young University in Provo, University of Utah in Salt Lake City, and Utah State University in Logan. These three universities collectively are referred to as the Utah Transportation Center. The partnership of the Federal Highway Administration (FHWA) provided national perspective to this consortium through funding initiatives and by helping to guide the objectives and scopes of the individual research projects. Other ex-officio partners to the test bed include Wasatch Constructors, Penhall Company, Terracon, numerous consultants and many other private contributors. The combination of government, academic and private sector interests created a very innovative environment and resource pool to get the most possible from the limited funding available.

The Test Bed consortium developed a work plan for the Phase 2 funding that was earmarked and appropriated under the Federal TEA-21 legislation for the 1999 fiscal year. This work plan was submitted to the Federal Highway Administration (FHWA) in September of 1998. It was utilized by the FHWA, UDOT and their university research partners to set Phase 2 research priorities for the I-15 corridor.

The Test Bed consortium is directed by an executive committee made up of the consortium universities, UDOT and the FHWA. Current voting members of the committee and their affiliation are as follows:

NAME	AFFILIATION / TITLE
Doug Anderson, Chair	UDOT, Director of Research
Loren Anderson	USU, Civil Engineering Department Chair
Jon Bischoff	USU, Geotechnical Specialist Engineer
William Gedris	FHWA, Structural Engineer
Larry Reaveley	UofU, Civil Engineering Department Chair
Boyd Wheeler	UDOT, Assistant Chief Structural Engineer
Leslie Youd	BYU, Civil Engineering Department Chair

William J. Grenney (USU), director of the UTC and Kevin C. Womack (USU) were appointed as ex-officio members of the committee. Dr. Womack was to serve as the administrator. The executive committee was the group that made the final decisions regarding priorities of proposed research studies that would be conducted under this program on the I-15 corridor using the allocation of the research funds received from the FHWA through TEA-21 legislation.

CONSTRAINTS OF THE DESIGN/BUILD PROCESS

The nature of the design/build process is intended to foster efficiency while maintaining a high level of quality. Therefore, the contractor must inherently be allowed some flexibility to institute changes in the design and construction schedule as the work progresses. However, the focus and degree of flexibility exercised by the contractor is not necessarily conducive to performing research in a design/build environment.

In addition to this inherent conflict, there were a number of other preconceived notions and institutional barriers that had to be overcome in order to conduct research in connection with the I-15 Reconstruction Project. Several approaches were undertaken to mitigate conflicts and to topple barriers.

First, support was developed within the Department for a research agenda. This was done by reaching a degree of unanimity between the research community and the end users as to what research would be useful and feasible to perform. Then, the I-15 project team had to be convinced that a research agenda would not cause adverse risk to the project budget or schedule. Parallel to these efforts, funding sources were sought to support a research agenda.

Once the research agenda was recognized as both feasible and desirable, a provision was included in the design/build request for proposals that notified contractors that the Department intended to conduct research and invited their cooperation and partnership in its accomplishment. One of the selection criteria was the degree of willingness exhibited by the bidder to assume a partnering stance. It turned out that the successful contractor was the one that submitted the most favorable plan for partnering on many issues, including research.

The final step required to clear the way for the research agenda to happen was the establishment of a research management protocol between the contractor, UDOT's I-15 Project Team and UDOT's Research Division. The objectives of the protocol were to protect the contractor and the project from overruns in cost or schedule that could be attributed to research activities, as well as to assure that safety and other risk management issues would be addressed by the research participants. Objectives from the research perspective were to allow collaborative agreements with subcontractors and other third parties and to reduce bureaucracy by permitting decision making to occur at the lowest level possible. After substantial negotiations the following protocol was agreed upon and included in all research contracts:

- The research activity shall not impact the cost of the D/B project;
- The research activity shall not impact the critical path schedule of the D/B project;
- If conflicts in the work schedule inadvertently arise between research activities and that of the D/B project, work under the D/B project shall take precedence;
- Research schedules and employment of subcontracts for research activities shall be coordinated with and agreed upon by both the UDOT and the contractor at the segment (lowest) level;
- The contractor's segment project managers shall determine coordination protocols to be followed in their segments; and,

- All personnel associated with or employed as part of the research activity shall undergo a safety orientation provided by UDOT or the contractor. In addition, if research activities are conducted immediately adjacent to or on railroad property or right-of-way, these personnel shall undergo a safety orientation approved by the railroad. The research participants shall agree to abide by and enforce the safety requirements of UDOT, the contractor, and the railroad as applicable.

While the above steps were key to opening up the possibility for research to occur on the I-15 corridor during reconstruction, several other factors contributed to its ultimate success. One of these were collaborations with strategic subcontractors associated with the D/B project, particularly those responsible for demolition and for geotechnical testing. In many cases these contractors had control of both the work site and the schedule, which made their participation almost mandatory. Also, they were more highly motivated than the general contractor to take the risks associated with the relatively smaller sized research activities in order to add to their work volume. The downside was that their participation was not always obtained at the lowest possible cost.

Another factor that had to be addressed was UDOT's research contracting process. Prior to this program, contracting for research was performed by either the Consultant Services Division or the Procurement Division of UDOT. Their processes were designed either for architect/engineer services or large annual purchases of equipment and materials. Also, the Research Division had to compete with many others in the department for the available resourses of these two divisions. In order to be both more responsive and more flexible under the design/build scenario, the Research Division took over the contracting task for research projects. This greatly facilitated working with the subcontractors and others on time critical research activities under this program.

PHASE 1 PROGRAM

As Phase 1 of this program was being conceived and initiated, clear funding sources were not readily apparent from traditional state or federal sources. Therefore, researchers were encouraged to seek out innovative funding sources for their studies. This was done to a remarkable extent, although the Phase 1 program became only a third the size of the Phase 2 program proposed herein. A complete description of Phase 1 of the I-15 National Test Bed Research Program is given in Report No. UT-99.03. The total budget for the Phase 1 program was $841,148 of which $200,000 or about 24% was granted by FHWA through their structures research program. A brief synopsis of the individual research activities conducted under Phase 1 is given below:

- **Full Scale Beam/Column Reinforcement with Carbon Fiber Composites**- A series of push-over tests were performed on I-15 bridge bents at South Temple. The information will be used to understand the capacity of existing bridges, and the use of composites in retrofitting bridge components. (U of U);

- **Bridge Deck Reinforcement with Carbon Fiber Composites**- Bridge deck specimens taken from structures scheduled for demolition on I-15 are being used to test the strength gain and fatigue resistance obtained from composite reinforcing. Various vendors have been evaluated in a series of laboratory tests. (U of U);

- **Forced Vibration Testing-** The South Temple bridge on I-15 was vibrated at various stages of capacity, and the resulting responses in the bridge components were measured. A new non-destructive method may be developed by analyzing bridge signatures. (USU);

- **Geopier Foundation Test-** An evaluation was conducted at the South Temple bridge site on I-15 during the pushover testing. These foundations were found to provide good support for certain types of soil conditions and loading levels. They appear to be very cost-effective compared to other foundation types. (U of U);

- **Wick Drain Performance Delay**- Instrumentation was placed to evaluate the effects of wick drain spacing and foot configurations on the delay caused by installation of wick drains in fine grained materials. (Richard Landau);

- **Ground Penetrating Radar for NDE of Bridge Decks-** Specimens of bridge decks that were being taken out of service were extracted before demolition and shipped to the FHWA's research facilities in McLean, Virginia. There, they will be used to help calibrate various GPR technologies. In addition, the HERMES GPR system will be exercised on in-situ bridge decks before demolition. (FHWA);

- **Bridge Superstructure and Substructure Corrosion-** Selected bridges being taken out-of-service are being studied to determine the effectiveness of various corrosion prevention and repair methodologies including epoxy coated rebar, precast beam end coatings, cathodic protection, and bonded overlays. (Corrosion Control Technology); and,

- **Evaluation of I-15 Design Build Project**- A consultant is monitoring lessons learned related to the innovative aspects of the I-15 project under Special Experimental Project 14. The evaluation includes best value selection & award process, performance specifications, QC/QA, owner controlled insurance, innovative construction processes, public relations program, progressive design methods, award fee schedule, and extensive partnering emphasis. In-house evaluations include owner-controlled insurance, methods to accelerate settlement of fills, immediate payment of invoices, use of advanced materials, organizational management structure, and right-of-way acquisition. (In-house & Carter-Burgess).

PHASE 2 PROGRAM

Phase 2 of the I-15 National Test Bed Research Program consists of some new studies as well as some extensions of other studies that were performed under Phase 1. These extensions of Phase 1 studies either expanded the number of parameters that had been considered under Phase 1 or demonstrated and implemented Phase 1 proof-of-concept findings. The scopes of most of the studies were developed by UDOT's university research partners as found in an unpublished report by the Utah Transportation Center entitled, *Structural and Geotechnical Research on the I-15 Corridor, Salt Lake City*, dated September 29, 1998. The final list of projects was a result of extensive reviews and negotiations between UDOT, the FHWA and the university research community. Projects were prioritized based on several factors, including applicability to the national strategic research agenda, urgency dictated by the timing of the I-15 Reconstruction Project, and availability of funds.

Table 1 summarizes the funding for Phase 2. Note that Phase 2 is nearly three times larger than Phase 1 and has a larger portion (51%) coming from the FHWA through their structures research program. These funds resulted from a special appropriation under TEA-21 legislation that recognized the unique opportunity afforded by the I-15 Reconstruction Project. These funds were won through a collaborative effort between UDOT their university research partners. Also shown in Table 1 are sources of matching funds over and above the minimum 20% state match required under TEA-21. These include UDOT's annual state and federal (SPR) research programs as well pooled funds from other states and from the private sector.

Table 1

I-15 National Test Bed, Phase 2

Research Program Funding Sources

Funding Sources	Funding Amounts	Total Funding
TEA-21 FY 1999 Funds:		
FHWA Research	$1,200,000	
State Match	$300,000	
Subtotal TEA-21 Funds		$1,500,000
Other Funding Sources:		
Federal Planning & Research (SPR)	$593,000	
State Construction	$49,000	
State Pooled Fund Contributions	$158,000	
Other Public Funds	$35,000	
Other Private Funds	$25,000	
Subtotal Other Funds		$860,000
Total Program Funding		**$2,360,000**

The funding would be allocated to each Phase 2 research project as shown in Table 2. A more detailed budget cost estimate is given at the end of each of the research work plans given herein. The costs shown include those incurred by the Department in managing and coordinating each research activity. In addition, the cost of insurance incurred under the new Owner Controlled Insurance Program (OCIP) is included in the Department costs. This insurance program was first instituted as a cost saving measure on the I-15 Reconstruction Project. In the first year it had been shown to be so successful that an OCIP was developed for all Utah State Contract Activities. As a result, insurance costs are now tracked on a project basis and have been included in the cost for each research activity shown herein. In addition, a contingency item is included in order to fund urgent or high priority projects that are unforeseen at this time. Such a project and its scope will be negotiated with the FHWA prior to its use.

MANAGEMENT OF RESEARCH STUDIES

In accordance with federal regulations, the UDOT Research Division has developed and implemented a management plan (Report No. UT-95.10) for its research, development and technology transfer programs. The customers of UDOT's Research Division are primarily the end users of the research findings, both inside and outside of the Department. In order to provide the greatest possible service to these customers as well as to achieve most value for the research investment made, the Research Division staff performs several managerial functions on all research projects (over $10,000) that it funds. These tasks include:

- Develop research contract documents and monitor technical & fiscal progress;
- Organize technical advisory committees (TAC);
- Assist principal investigator in development of technical working plans;
- Facilitate meetings between the TAC, the D/B contractor and the research teams
- Coordinate field activities with the D/B contractor and with other researchers;
- Process contract deliverables for review;
- Distribute published findings; and,
- Perform long term technology transfer activities.

As mentioned earlier, in order to improve the contracting process, the Research Division has taken over the function of developing research contracts from other divisions in the Department. This was necessary in order to be more responsive to the design/build reconstruction project schedule and to maintain controls over coordination with the D/B contractor as well as on cost and schedule.

The technical direction of the study and the competency of the findings are monitored by technical advisory committees (TAC). Committee members are chosen carefully to get a balance between researcher and end user perspectives. Sometimes out-of-state technical experts are invited to participate in special areas of interest. The TAC reviews the initial work plan and offers guidance throughout the study. The Research Project Manager facilitates meetings of the TAC and coordinates the review process.

Research contracts are generally written on a lump sum basis. Cost overruns are not allowed unless a change in scope is authorized. This requires the development of a detailed work plan, staffing plan, schedule and budget for the study, which must be agreed upon up front. Payment is made based on a list of deliverables. Research Project Managers assist the principal investigators in development of this work plan, which then becomes part of the contract documents.

One of the key functions performed by UDOT's Research Project Managers is coordination with the D/B contractor. This starts with identifying potential sites on the I-15 corridor that could be useful in performing research tasks already identified. The next challenge lies in determining schedule feasibility. All this has to occur before research contracts can be finalized. Research Project Managers also are required to perform liaison between the research team and the D/B contractor in order to minimize point-of-responsibility conflicts. Opportunities for potential conflicts to arise are abundant once field work commences.

The responsibility of Research Project Managers for their project does not end when all the contract deliverables are submitted and the contract is closed out. They also have the responsibility for publishing and distribute the UDOT final report. Also, they are charged with continuing to performing technology transfer activities for up to two years after the work is complete, or until implementation is achieved. Thus, they become the primary steward to help assure that investments in research eventually pay off.

81F15021 – Push-Over Test of Bridge Bent with Advanced Composites Reinforcement, Phase 2

Funding Source:	FHWA Research (TEA-21 FY 1999)	$ 237,920
	State Match (TEA-21 FY 1999)	$ 59,480
	*Total Cost Estimate	$ 297,400

Principal Investigator: Chris Pantelides, University of Utah

Research Project Manager: Steve Bartlett

*Based on actual projected amounts for Research Division personnel and other costs. Matching amounts from other agencies are based on information provided by others and may not include all costs.

PROBLEM DEFINITION

Seismic rehabilitation techniques involving steel jacketing, concrete jacketing and composite material jacketing for bridge columns are currently implemented on a routine basis. Design equations have been developed for the retrofit design of columns with bonded or unbonded fiber reinforced polymer (FRP) composites. External plate bonding technology on the surfaces of concrete members such as beams and joints, which originated with steel plates, has been tested but has not matured to the same level of knowledge as columns. The effectiveness of externally applied composites in improving the flexural and shear capacity of reinforced concrete beams has been recently demonstrated. Design equations have been proposed for the retrofit design of beams with bonded FRP composites. Retrofit of reinforced concrete beam-column joints using externally applied FRP composites is an area of relatively new research. A limited number of experiments have been performed both in the laboratory and in-situ for bridge beam-column joints. The results are encouraging, and preliminary design equations have been developed.

Future applications of FRP composite technologies for rehabilitation of bridge structures will have to be developed in terms of a complete bridge system rather than at the component level. Knowledge gained from the recently completed in situ tests at Interstate 15 is invaluable in approaching the retrofit of the bridge at the system level. A synthesis of knowledge regarding structural concepts ranging from the confinement of columns using FRP jackets, the flexural and shear improvement of beams using FRP plates and wraps, the improvement of the shear capacity of joints using FRP wraps, and the tension tie capacity provided by FRP composite strips needs to be made. In addition, serious consideration needs to be given to the pile/footing system and its connection to the bridge bent. In summary, future rehabilitation of bridges with composites must provide a complete load path from the deck to the earth; it is imperative to understand the superstructure/substructure/foundation system, as a complete system.

This research study addresses the following issues:

1. Lateral load capacity of existing bridges
2. Lateral load capacity of bridges after jacketing of columns, beam cap and beam cap-column joints with composites
3. Demand/Capacity ratio of existing and retrofitted bridges
4. Cyclic pushover test of bridge with soil structure interaction

The Composites Structures Group at the University of Utah has completed three projects relevant to the present study. These are:

(1) ***Highland Drive Bridge at Interstate 80 Demonstration Project*****:** The application of carbon fiber composite jackets for the three columns and cap beam of an existing concrete bridge pier, at the Highland Drive Bridge on Interstate 80 in Salt Lake City, was performed in September 1996. The evaluation of the pier in the as-is condition, the rehabilitation objectives, and the composite wrap design were investigated. A bilinear stress-strain curve for the confinement model of circular and rectangular concrete sections with carbon FRP composite jackets was developed for performing pushover analyses.

A displacement-based approach was used to design the carbon fiber composite wrap for the bridge bent and four full-scale specimens. The demonstration project has shown that the retrofit of a bridge pier of a typical bridge, built before seismic requirements became effective, for gravity and seismic loads is feasible. The advantage of this external composite retrofit is that it is fast, non-intrusive, and does not increase the weight of the pier as compared to the encapsulation technique.

(2) ***Beam-column Joint Tests*****:** A total of fifteen beam-column joint tests at a 1/3-scale were performed at the University of Utah Structures Laboratory in 1997. Eleven of these tests were performed with externally bonded carbon FRP composite sheets of various configurations. In addition, four baseline tests were performed without composites for comparison. It was found that the FRP composite enhances the joint's shear capacity, and improves the overall damage control. The important parameters identified in the study included surface preparation, fiber orientation, extension of composite sheets, and number of FRP layers.

(3) ***South Temple Bridge In-situ Tests on Interstate 15*****:** The University of Utah conducted three in-situ tests at the South Temple Bridge in Salt Lake City in May and June 1998. These included a test of a bridge pier in the as-built condition, a test of a pier in the as-built condition retrofitted with advanced composites, and a test of a damaged pier retrofitted with advanced composites. The purpose of the tests was to determine the strength of FRP wrapped beam-column joints, and the improvements that could actually be achieved using a carbon FRP seismic retrofit. The retrofit included elements of strengthening the existing foundation system of the pier.

The design of the retrofit and the composite were performed based on rational design criteria. These criteria included design equations for column retrofit developed at the University of California San Diego. A design equation for retrofitting beam-column joints was developed at the University of Utah as a result of the *Beam-Column Joint Tests* and the present study. The confinement model for circular and rectangular concrete members, developed for the *Highland Drive Bridge Interstate 80 Demonstration Project*, was used in the analytical simulations for verification of the design. The design was targeting a specific displacement ductility, which was twice that of the as-built pier.

Good correlation between analytical and experimental results was observed which included the yield level of the members, the peak lateral load, and the location of plastic hinges. The FRP composite was able to strengthen the cap beam-column joints effectively, the ductility was increased sufficiently close to the designed level, and the lateral load capacity of the pier was also increased. The tests showed that significant improvements in the seismic capacity of existing piers could be achieved by incorporating FRP composites with proper retrofit of the foundations. This is true for both undamaged and damaged bridge piers from recurring earthquakes.

OBJECTIVES

The objectives of the project will be achieved through in-situ field testing of the South Temple Bridge on the I-15 corridor, and analytical/design capabilities at the Department of Civil & Environmental Engineering at the University of Utah. The major objective of this research is to test the in-situ load-displacement capacity of a seismically retrofitted multicolumn bridge bent including its foundation system. This retrofit is to be achieved independent of the loading mechanism, so that the bent and foundation will resist all forces and displacements on its own. Thus, the test of the retrofit measures will more closely correspond to realistic earthquake effects on a seismically retrofitted bridge. For comparison purposes, a second bent in the as-is condition without any retrofit will also be tested. This bent will support identical gravity loads as the retrofitted one, since the two bents will be supporting the deck between them. Finally, a third bent in the as-is condition shall be tested but unlike the second test, this bent will not support any gravity loads. Thus, a comparison with the second bent will be possible. The specific objectives of this research program are as follows:

Objective 1: Capacity and Ductility of Retrofitted Bent

Before testing predict the load capacity and ductility of the retrofitted bent. This involves the determination of the seismic demand on the bridge in terms of forces and displacements. The design spectra for the new bridges of the Interstate 15 reconstruction shall be used; both the 10% exceedance in 50 years and the 10% exceedance in 250 years design spectra will be used. The bridge bent will be analyzed in the existing condition. In addition, determination of the capacity of the bridge in terms of forces and displacements shall be made. The structural deficiencies of the bridge will be noted, and seismic retrofit measures shall be designed. These include *foundation rehabilitation*, which might involve thickening of the pile cap for improved shear resistance, anchorage of the piles to the pile caps, and compression/tension ties between the three pile caps. The retrofit measures will also include *column FRP jacketing*, and *cap beam and cap beam-column joint FFR jacketing.* The structural analysis will use the design spectra for the newly built I-15 bridges and involve soil-structure interaction effects and inelastic pushover analysis.

The retrofit measures determined from the above analysis will then be implemented. These will involve strengthening of the foundation, water jet and shotcrete operations to prepare the concrete for the FRP application. The FRP application will then follow and finally the test setup will be erected. Instrumentation and the actual test will follow. Testing is to be achieved independent of the loading mechanism, so that the bridge bent and its foundation system will resist all forces, as shown in Figure 1. Measurements of strain, load, and displacements at selected points during the in-situ experiments will produce data, which can be correlated to the theoretical results. A three-column bent shall be tested to implement and verify the goals stated above. The majority of the infrastructure, facilities, and instrumentation for tasks required to achieve this objective already exist. The load frame foundation is in place for the test.

Objective 2: Capacity and Ductility of Bent in the As-is Condition

There is a need to know what exactly **is** the capacity of the as-is bent. These bents which were build in the early sixties, have certain design deficiencies as compared to today's designs. In addition, corrosion and concrete delamination are present, but the actual capacity and ductility are not very well known. This is a unique opportunity to determine the strength and ductility of these types of bents. Before testing we shall predict the load capacity and ductility of the as-is bent. This involves the determination of the seismic demand on the bridge in terms of forces and displacements. The bridge bent will be analyzed in the existing condition. The only strengthening that will be attempted before the test is the anchoring of the pile cap to the piles by using epoxy and Dywidag bars. This is necessary, otherwise failure will occur prematurely at the interface between the pile cap and the piles, and determination of the lateral load capacity and ductility will not be possible. The structural analysis will use the design spectra for the newly built I-15 bridges and involve soil-structure interaction effects and inelastic pushover analysis.

Instrumentation and the actual test will follow. Testing is to be achieved independent of the loading mechanism, so that the bridge bent and its foundation system will resist all forces, as explained in Objective 1. Measurements of strain, load, and displacements at selected points during the in-situ experiments will produce data, which can be correlated to the theoretical results. A three-column bent shall be tested to implement and verify the goals stated above. Note that the bent will support identical gravity loads as the retrofitted one, since the two bents will be supporting the deck between them.

Objective 3: Ultimate Capacity and Ductility of Bent in the As-is Condition

In this case, a test will be performed for a bent in identical conditions as the as-is bent of Objective 2, with the exception that the bent will not carry any dead load. This is because the deck will be removed. The details of the test will be identical with the test described in Objective 2. Thus, a comparison between the two cases will be achieved.

Objective 4: Cyclic pushover tests of bridge with soil structure interaction

A better understanding of the seismic performance of the soil-structure interaction effects for bridge bents supported on piles is desirable. This will be obtained using the three tests described above along with measurements of the displacements of the pile caps and piles. The analysis will include spring models for both the pile as well as the soil vertical, horizontal and rotational resistance. Once the tests are completed, these models will be verified and calibrated to closely represent the results obtained from the tests. The geotechnical tests will be measuring vertical and horizontal deformations of the pile caps.

Objective 5: Assessment of Retrofit Success

This phase involves the data reduction from the tests in terms of evaluation of the experimental results, and determination of the success of the retrofit measures. The latter will involve assessment using analytical techniques utilizing in-situ strengths of the materials, and measured limiting forces, displacements and strains. The theoretical assumptions of the inelastic behavior of concrete will be verified using analytical tools such as nonlinear pushover analyses, and evaluation of corrosion effects in the capacity of structural members such as these. Finally, using the results obtained from the previous three objectives, improved recommendations on *Design Guidelines* for complete for seismic retrofit of R/C bridges similar the one tested will be made.

The objectives outlined above build on previous work performed by the investigators. However, the actual testing differs from the previous work in that the bridge is completely uncoupled with respect to the footings of the loading system. The previous tests were designed to capture the behavior of the cap beam-column joints retrofitted with composites, and as such they were not designed to test the behavior of the entire structural system, including the pile caps and piles. However, the investigators verified the absolute necessity for the seismic rehabilitation of the bridge foundation and piles during their previous tests. In addition, the tests described in the current proposal more closely represent the expected behavior of the bridge bents in the as-is or retrofitted condition in a seismic event. The testing is important because it will allow for the development and verification of improved design procedures using conventional and advanced composite materials. These procedures could be utilized immediately for projects such as the repair of the bridges on the Interstate 80 corridor.

BENEFITS

The research activity for this proposal will enhance the existing knowledge base in the following areas:

- Advances in FRP design methodologies and application procedures, which have the potential of reducing the material required for retrofit, thus increasing the cost effectiveness and rapidity with which structurally deficient bridges can be repaired. It is important to recognize that first the deficiencies associated with advanced corrosion will be addressed and included in any rehabilitation work. Subsequently, deficiencies due to service loads (columns, cap beams, cap beam-column joints), as well as seismic forces (columns, cap beams, cap beam-column joints, foundations, pile-foundation connection) will be addressed.

- Complete seismic bridge bent retrofit procedures including the foundations, columns, cap beam, and beam-column joints. In particular, the seismic retrofit of the pile cap to pile system for both vertical as well as horizontal loads is emphasized. Improvements in modeling of the entire system which include corrosion effects, soil-structure interaction effects, and cost effectiveness comparisons of various levels of foundation rehabilitation will be achieved.

- Refinements in construction techniques and procedures such as water jet, shotcrete, ambient temperature wrapping and jacketing of the FRP composite, and anchorage of the FRP to the concrete. These are important issues in the field application, upon which the effectiveness of the retrofit depends on. For example, bonding of the carbon to concrete is critical in the cap beam and joint areas.

- Comprehensive retrofit design guidelines for the complete bridge using FRP composites and other proven techniques. These guidelines include retrofit for corrosion-related deterioration for regaining the functionality of the bridge for service and fatigue loads, as well as guidelines for seismic retrofit for various performance levels.

The results of this research will be disseminated to FHWA and UDOT engineers. In addition, the results will be presented at National Conferences such as the Transportation Research Board Annual Meeting, the National Seismic Conference on Bridges and Highways, and others. Several journal papers will be submitted to the ASCE Journal of Structural Engineering and the Journal for Composites in Construction.

MAJOR TASKS

Overview:

The bridge under consideration is located at the South Temple Street Overpass on Interstate 15. In particular the Southbound Bridge is of interest (Bridge 58 in the UDOT drawings). The bridge has 8 bents and 9 spans. The tests will require the use of only three bents, Bent 4, 5 and 6. The deck between bents 5 and 6 will also be required. The reasons for choosing these three bents is that for Bent 6 the foundations of the load frame already exist, from last year's tests. In addition Bents 4 and 5 are out of the Wasatch Constructor's critical construction path.

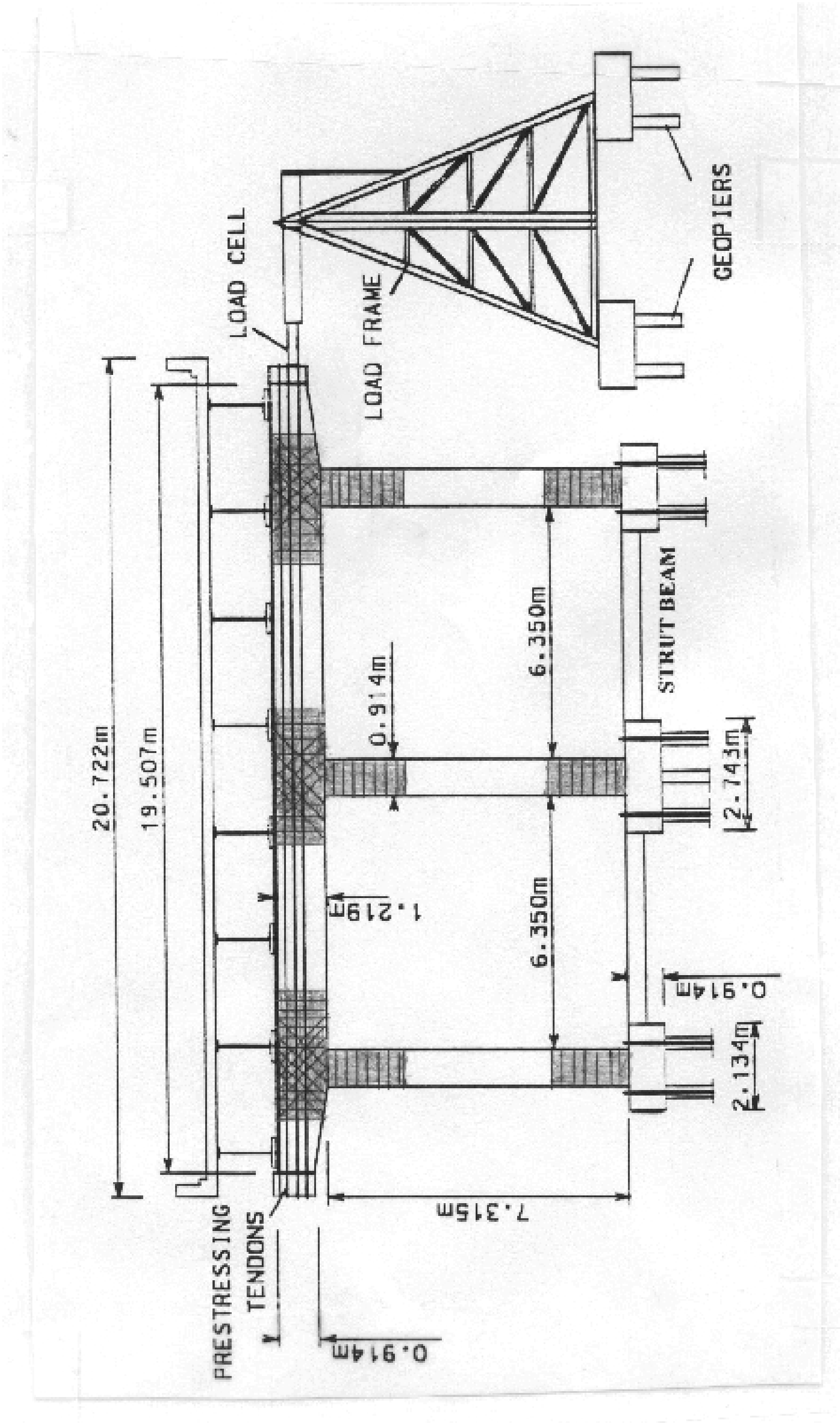

Figure 1. Proposed Test Configuration

In conjunction with the structural tests, geotechnical instrumentation will be installed and monitored to determine movements of the pile caps, reaction frame footings, piles and Geopiers supporting the reaction frame footings during the lateral loading of the bridge bents, as well as other loads, stresses and deformations of selected components of the foundation systems. The bent pile caps will not be tied laterally to the reaction frame footings during these structural tests to obtain the true forces and displacements on the retrofitted bents. Reactions of foundation system, soil pressures, and lateral deformations of the substructure and superstructure components will be measured relative to load applied during this test. This will enable the performance of Objective 4, soil-structure interaction studies. The following three tests will be carried out:

1) Test of Bent 6 with the carbon fiber retrofit and deck i n place.
2) Test of Bent 5 in the as-is condition and deck in place.
3) Test of Bent 4 in the as-is condition with deck removed.

Task 1: Prepare field specimens, install instrumentation and conduct tests.

Perform full-scale field tests and collect data for Bents 4 and 5 in the as-is condition, and Bent 6 retrofitted/repaired with carbon fiber composites as shown in Figure 2. The rehabilitation with carbon fiber composites will consist of wrapping critical areas of the columns, bents, and joints between the cap beam and the columns, to ensure ductile behavior. Bending and shear strength, and deformation ductility levels will be obtained for the bents in the as-is condition and the bent with carbon fiber composites. The testing will require separate footings for Bents 4 and 5, which will rest on piles, and Geopiers. The load frame to be used in the tests already exists from previous testing. Bent 6 will be cleaned, shotcreted and reinforced with the carbon fiber composite using full scaffolding.

Cyclic quasi-static tests will be performed for the two bents using the arrangement shown in Figure 3. The cyclic tests will start with force controlled push and pull cycles. Each force level cycle will be repeated three times as shown in Figure 3. After the first yield, the loading will be displacement controlled as shown, with increments of ductility of μ =1, 1.5, 2, 2.5, etc., up to the point where the applied load will drop 20% from the value of the peak load. The loading system consists of a Hydroline actuator owned by the U. of Utah, which will be connected together by means of a loading head as sho wn in Figure 1, and a stand-alone hydraulic power supply. The actuator has a push capacity of 400 kips, and a pull capacity of 400 kips. The maximum stroke is 30 in. one way, or ± 15 in. two way.

The actuator will be supported by the steel load frame as shown in Figure 1. The steel frame is composed of two A-frames linked by bracing and it has dimensions of 24’x20’x6’. The U. of Utah owns the load frame, which is already on the site. The steel frame will be anchored to the concrete foundation, which will be built on the side for Bents 4 and 5. Bent 6 already has a foundation built from the previous tests.

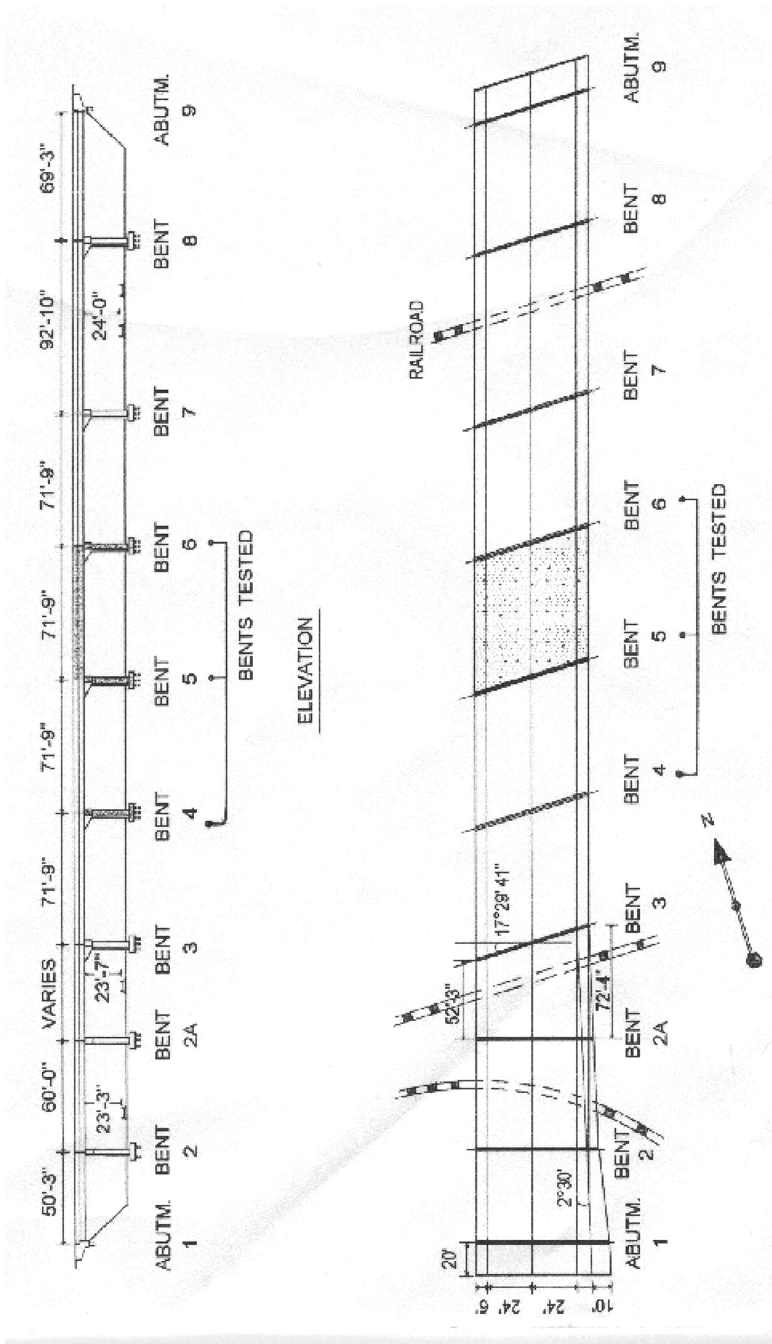

Figure 2. Bents 4, 5, and 6 on Southbound South Temple Bridge

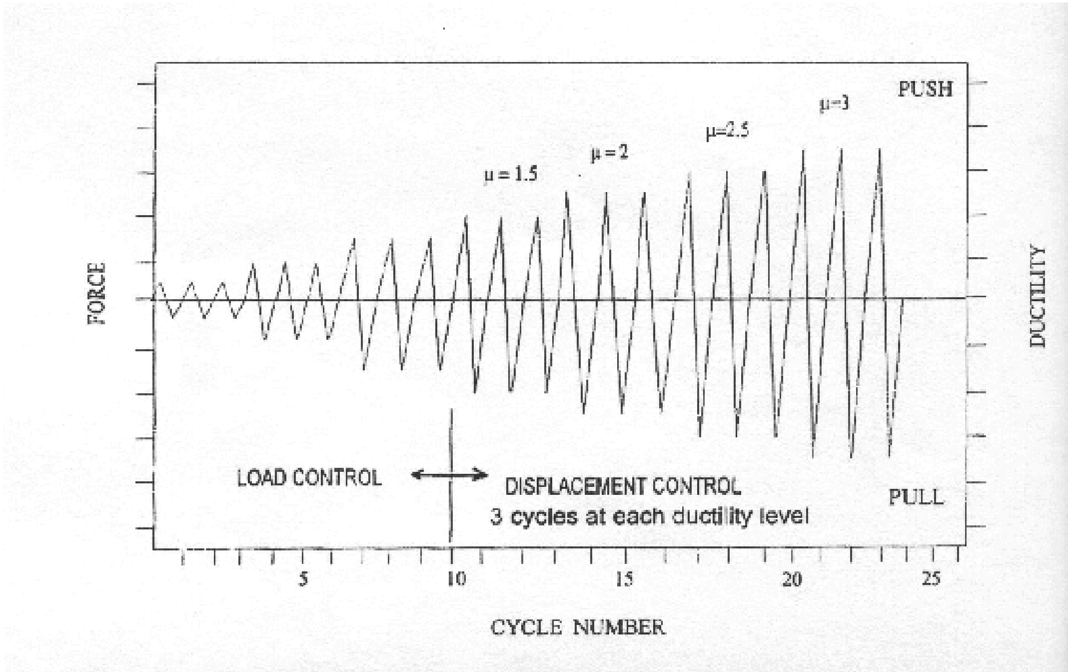

Figure 3. Loading History

The data acquisition system will consist of measurements of tensile strain in the rebar, shear strains in the concrete at the joint, as well as the tensile strains in the carbon fiber composite. The location of the strain gages and LVDTs is shown in Figure 4. In addition, the horizontal displacements of the columns, and the horizontal and vertical displacements of the cap beam, and the cap beam-column joint will be measured using displacement transducers. The displacement transducers shall be fixed to supporting scaffold.

Task 2: Reduce and analyze test data; Calibrate theoretical models.

The design of the carbon fiber was based on ductility demand. The goal of the design shown in Figure 1 is to approximately double the ductility of the bent in the as-is condition. Calibration of the theoretical predictions in the Objectives will be performed after the tests. In addition, the difference between the in situ capacity and the theoretical capacity of the as-is tests of Bents 4 and 5 will be evaluated. Such studies will provide greater understanding of the factors contributing to the response and a benchmark for validating the accuracy of the analytical modeling techniques. The calibration involves assumed material properties and stress-strain relations. Calibrate the predicted shear capacity of the cap beam-column joint retrofitted with carbon fiber composites using the test results. Develop a simplified analytical procedure for predicting the pushover capacity of both the bent in the as-is condition and the bents with carbon fiber composites.

Task 3: Perform demand/capacity studies. Modify FRP design guides.

From the updated structural models and the test results, obtain demand curves for the 10% exceedance earthquake for the 50 and 250-year events. Plot the capacity and demand for both the as-is and FRP retrofitted bents and determine the benefits derived from the retrofit. Using the results of the tests and the calibrated models developed above, develop revised design guidelines for composite retrofit.

Task 4: Document and publish findings.

The findings of this research project will be disseminated through a number of separate reports and publications. These will include interim and final reports to the DEPARTMENT as well as AASHTO technical committee presentations and TRB publications.

PROCEDURES FOR PREPARATION, INSTRUMENTATION, AND TESTING

Before testing the following items must be completed:

a) Fencing of site to protect the instrumentation and equipment from vandalism.
b) Surface preparation of cap beam for Bent 6. This entails taking off the 2-in. cover from the cap beam because it is in loose state. This can be achieved using water jet, and jackhammers.
c) Shotcrete the cap beams to cover the rebar and form smooth surface to apply the carbon fiber composite.
d) Surface preparation of columns and cap beams in terms of rounding of the corners for application of carbon fiber composite.
e) Application of carbon fiber composite. This will involve hand-lay-up of the composite for both the columns and the cap beam using room temperature cure. Depending on the weather it may be necessary to use heaters and covers for the bend during curing of the composite.
f) Connection of pile caps and piles with Dywidag post tensioning bars. This is necessary for improving the tensile capacity of pile cap–pile connections. Currently, the piles are connected to the pile cap with only four #6 bars which is not adequate for the uplift forces expected to be developed during the tests. Each bent will require 16 - 1 ¼ in. threaded bars epoxied into the piles and pile cap, and fastened by plates 7x7x1 ½ in. on top of the pile caps.
g) Connection of actuator to cap beam. This will be done with steel plates and post-tensioning strands. Removal of steel girder bearings on top Bent 6. The girders are pinned on one bent and simply supported at the other bent. Thus, there is a real possibility that the girders will be displaced sufficiently during the tests and fall off the cap beam if the displacement of the bent is large. Therefore, removal of the bearings of Bent 6 and fixing the bearings on Bent 5 shall be performed. This works as demonstrated in the previous tests.

Instrumentation will consist of the following types at the locations indicated:

a) Instrumentation of bents. This will entail strain gages in the column and cap beam rebar, displacement transducers, and LVDT's at the joints to measure average strains. These instruments as well as the 80-channel data acquisition system have been calibrated. Verification will be provided at the site to ensure that this instrumentation is working.
b) LVDTs and/or displacement transducers and independent reference frame to measure horizontal and vertical deformations of the reaction frame footings during the tests.
c) Additional instrumentation for geotechnical measurements as found in the related proposal from the Geotechnical group submitted by the U. of Utah and BYU..

The procedures and criteria that will be used during the tests are as follows:

a) Measurements will be taken at a frequency of 60 measurements per minute.
b) The completion criterion for the tests will be when the bent loses 20 % of its peak strength.
c) The post-test verification of instrumentation will involve checking the physical condition of the instruments, and their maximum working range.
d) Reduction of the structural data from the structural tests will involve the drawing of hysteresis loops for each test, selected histories of strain gage measurements and LVDT's.
e) The actuator, data acquisition, and instrumentation will be covered where necessary for falling debris protection with plywood.
f) Removable equipment will be removed and stored in a safe place.
g) After testing, cores will be taken and tested to determine in-situ properties of concrete. In addition, steel rebar and carbon fiber will also be tested according to ASTM standard tests to determine their actual strength and stiffness properties.

STAFFING AND SUBCONTRACTING PLAN

The research team at the University of Utah, Department of Civil and Environmental Engineering, includes the following personnel:

Chris P. Pantelides, Ph.D., P.E.
Lawrence D. Reaveley, Ph.D., P.E. It is anticipated that two graduate and two undergraduate students will participate in the project.

However, successful completion on this research also depends on the cooperation from and successful completion of the research programs of Professor Kyle Rollins by Brigham Young University and Professor Evert Lawton from the University of Utah, all of which are being performed at the same site. In addition, the field portion of the study must be closely coordinated with Penhall Company, the demolition subcontractor for the D/B Reconstruction Project.

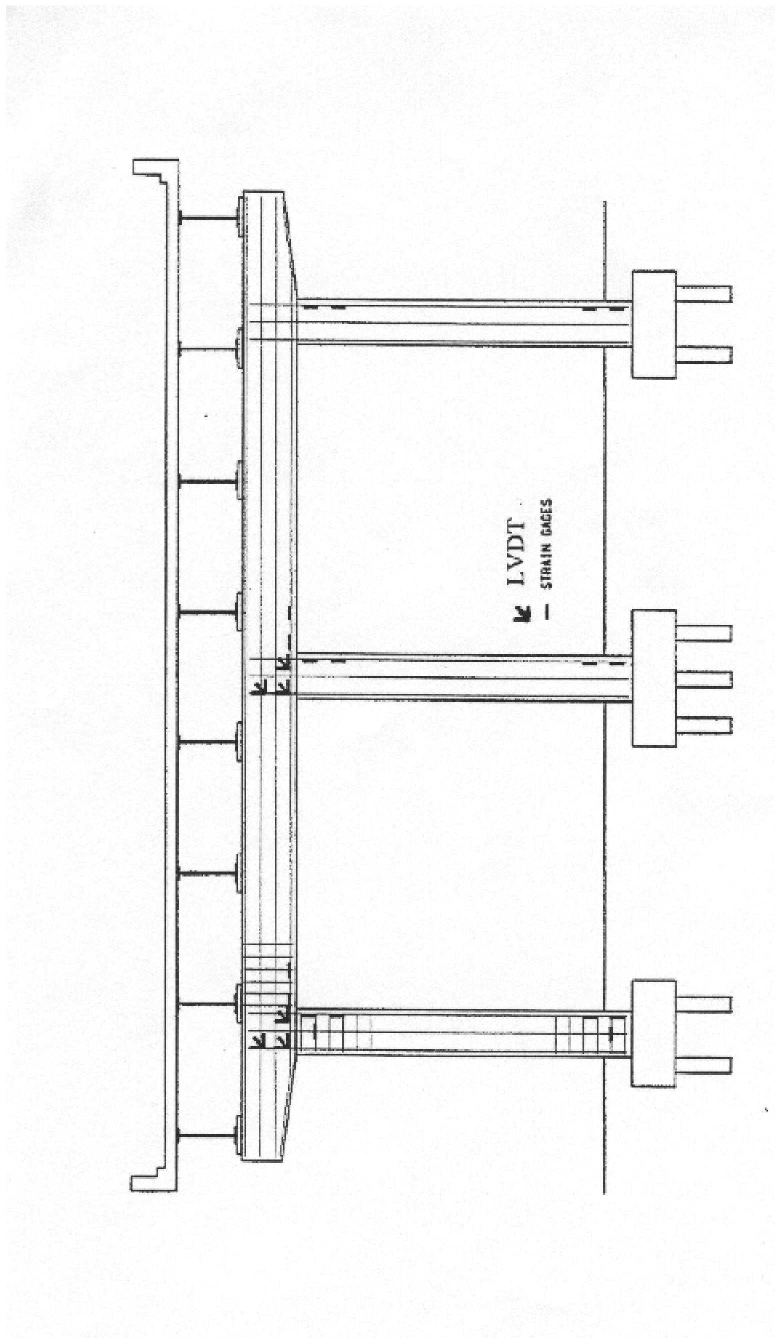

Figure 4. Location of strain gages and LVDT's

The investigators from the University of Utah will subcontract part of the work to the following entities:

Boetcher & Sons:	Remove bearings and welding.
Commercial Design & Construction:	Construction of reaction footings.
Crossroads:	Erect and dismantle load frame.
Judd Jones:	Application of shotcrete and scaffold.

Valley Systems:	Water jet surface preparation.
Xxsys Technologies or other:	Carbon fiber composites application.

SCHEDULE

Within two weeks after notice is given to proceed, a detailed schedule shall be submitted to UDOT showing a detailed breakdown of tasks and their order of completion in order to achieve the following milestones:

Activity	**Milestone Schedule (Contract Time After Notice to Proceed)**
Field Tests:	
Mobilization	1 Week
Water jet Bent 6	1 Week
Instrument Bent 6	2 Weeks
Instrument Bent 5	2 Weeks
Instrument Bent 4	2 Weeks
Pour concrete boxes around bearings of Bent 5	1 Week
Shotcrete Bent 6	1 Week
Composite Retrofit of Bent 6	1 Week
Demolition	1 Week
*Remove bearings and replace with rollers for Bent 6	1 Week
*Load system assembly	1 Week
*Test Bent 6	1 Week
*Test Bent 5	1 Week
*Test Bent 5	1 Week
*Test Bent 4	1 Week
*Dismantle and demobilization	1 Week

*Note: * denotes time-critical items*

Data analysis, parametric studies and Reporting:	
Results of literature searches and field tests	3 Weeks
Results of Constructability and cost studies	4 Weeks
Results of detailed research findings, data reduction, analysis and model calibration	20 Weeks
Final report	7 Weeks

The schedule shall be sufficiently detailed to track daily progress of activities during the field testing phase and weekly progress during the remainder of the contract. Critical path methodology shall be employed to determine time relationships between activities. The schedule shall be presented in the form of a Gantt Chart.

The investigators are aware that they will have only 6 weeks to perform the tests in the month of August. The schedule shall take into account the work of other contractors at the site, including Wasatch Constructors.

BUDGET SUMMARY

U of U Contract Costs:	
Personnel Direct Costs:	$ 81,326
Equipment, Materials & Other Costs:	$ 39,000
Subcontracts:	$110,856

Subtotal Contract Direct Costs, Equipment Etc. & Subcontracts:	*$231,182*
Indirect U of U Contract Costs:	*$ 23,118*

Subtotal U of U Contract Costs:	*$254,300*
UDOT Direct Costs:	
Personnel Direct Costs:	$ 5,000
Equipment, Materials & Other Costs:	$ 8,600
Subcontracts:	$ 29,500

Subtotal UDOT Direct Costs, Equipment Etc. & Subcontracts:	*$ 43,100*

Total Project Costs:	***$297,400***

81F15022 – Evaluation of Geopier Foundation Systems, Phase 2

Funding Source:	FHWA Research (TEA-21 FY 1999)	$ 177,440
	State Match (TEA-21 FY 1999)	$ 44,360
	Geopier Foundation Company (In-kind)	$ 25,000
	*Total Cost Estimate	$ 246,800

Principal Investigator: Evert Lawton, University of Utah

Research Project Manager: Steve Bartlett

*Based on actual projected amounts for Research Division personnel and other costs. Matching amounts from other agencies are based on information provided by others and may not include all costs.

PROBLEM DEFINITION

The performance of buildings and highway structures during an earthquake is critically dependent upon the ability of the foundation system to safely carry the loads generated by the earthquake. Most foundation systems are strongest in vertical compression and weakest in uplift and lateral capacity. Although fairly reliable methods have been developed for predicting the ability of different foundation systems to carry vertical compressive loads, less emphasis has been placed on determining the lateral and uplift capacities of these systems, particularly under dynamic loads. Owing to the high cost and logistical difficulty of conducting full-scale lateral and uplift tests on foundation systems, only results from a few full-scale tests are available in the open literature.

The availability of abandoned I-15 structures for full-scale testing prior to their demolition presents a unique opportunity to obtain ground-truth experimental results for pile foundation systems subjected to lateral, uplift, and compressive loads. In addition, an opportunity exists to compare the performance of pile foundation systems with other types of foundation systems. In particular, this opportunity has the potential to provide significant new and improved methods for designing and analyzing various types of foundation systems subjected to lateral and uplift loads.

OBJECTIVES OF THE RESEARCH

The primary objectives of this research are as follows:

1. Obtain ground-truth data for the horizontal and vertical movements of piles caps supporting existing bridge bents.

2. Determine the soil-structure interaction of existing bridge bents supported by pile foundations during cyclic lateral loading of the bent cap.

3. Obtain ground-truth data for the bending stresses that are generated in reaction frame footings during cyclic loads consisting of a combination of lateral forces, overturning moments, and alternating compression/uplift forces.

4. Obtain ground-truth data on the behavior of reaction frame footings supported by geopiers subjected to two types of cyclic loads: (a) Lateral forces only and (b) combined lateral forces, overturning moments, and alternating compression/uplift forces.

5. Obtain ground-truth data for single geopiers subjected to cyclic lateral loads.

6. Obtain ground-truth data on the behavior of shallow footings on unreinforced ground without and with backfill subjected to cyclic lateral forces only for similar conditions to the lateral forces only data obtained in part 1 for geopier foundations.

7. Determine what proportion of the total lateral force applied to shallow foundations bearing on unreinforced ground is carried by shearing resistance along the base and what proportion is carried by lateral passive pressure of the adjacent soil.

8. Determine what proportions of the total lateral force applied to footings supported by geopiers are carried by shearing resistance along the footing-matrix soil interface, shearing resistance along the footing-geopier interface, resistance provided by pulling the bottom uplift plates into the geopiers through the Dywidag bars embedded in the footing, and passive resistance provided by the backfill.

9. Determine the group effect for geopier foundation systems subjected to cyclic lateral loads, uplift loads, and combined lateral and compression/uplift loads. The group effect will be determined in terms of the center-to-center spacing of the elements and number of rows within the group.

10. Improve existing methods or develop new methods for the design and analysis of these foundations systems subjected to earthquake loads (combined cyclic lateral forces, uplift/compression forces, and overturning moments).

SUBSURFACE EXPLORATION, TESTING, AND ANALYSIS

Proper characterization of the subsurface materials are necessary to ensure that the foundation support systems are designed properly, the results from the full-scale field tests are interpreted correctly, and the numerical and theoretical analyses extending these results to other conditions are successful. The characterization of the subsurface materials in this research program will be accomplished by the following four-phased approach:

1. **Obtain as much existing information as possible regarding the subsurface materials and their properties at the sites.** Wasatch Constructors has a substantial amount of information available at the S. Temple site, on which some testing has already occurred. Substantial information has already been obtained, including eight geologic borings to an average depth of 33

m (110 ft), fifteen CPT borings to an average depth of 33 m (110 ft), fourteen consolidation tests on undisturbed samples from various depths, twenty six unconfined compression and fifty one Torvane tests on undisturbed samples from various depths, 119 downhole seismic shear wave tests at various depths, 37 tests to measure pore pressure dissipation with time at various depths using CPT cone, and preconsolidation pressure profiles and SHANSEP undrained strength parameters at the locations of four of the CPT borings.

2. **Conduct additional field testing at critical locations.** At least one Standard Penetration Test (SPT), one Cone Penetration Test (CPT), and one Borehole Shear Test (BST) will be conducted at the location of each newly constructed reaction frame footing to be supported by geopiers and at the location of each test on a single pile or geopier. At least one of each type of test will also be conducted adjacent to each existing pile cap that will be tested. Other types of specialty tests – including K_0-blade, pressuremeter, and dilatometer tests – may be conducted at selected locations if time and funding considerations permit it.

3. **Obtain samples for laboratory testing.** Undisturbed cohesive samples and disturbed cohesive samples will be obtained. Specimens will be prepared from these samples for various types of laboratory testing (unconfined compression, triaxial, consolidation, classification, etc.). Piston and block sampling techniques will be used to obtained undisturbed cohesive samples for this project.

4. **Conduct laboratory tests to establish the stress-strain-strength parameters of typical soil types.** Tests to be conducted on undisturbed cohesive specimens include one-dimensional consolidation, unconfined compression (UU), triaxial CU with pore pressure measurements, and triaxial CD. Triaxial CD tests will be performed on reconstituted cohesionless specimens. Results from these tests will be used to determine appropriate stress-strain-strength parameters for the numerical and theoretical analyses to be conducted after the field tests and data reduction have been performed.

FIELD TESTS

Types of Tests and Procedures

The following major types of field tests will be conducted:

1. Tests in which two newly constructed reinforced concrete footings and two existing reinforced concrete footings will be subjected to simulated cyclic earthquake loads consisting of a horizontal force (alternating in direction), a vertical force (alternating compression and uplift), and a moment (alternating direction) generated by the horizontal force acting on the top of the footing. The footings in these tests will be supported by geopiers. The footings will support a structural steel frame and hydraulic actuator that will alternately push and pull horizontally on the cap of existing I-15 bridge bents at the South Temple Overpass (see Fig. 5) prior to their demolition.

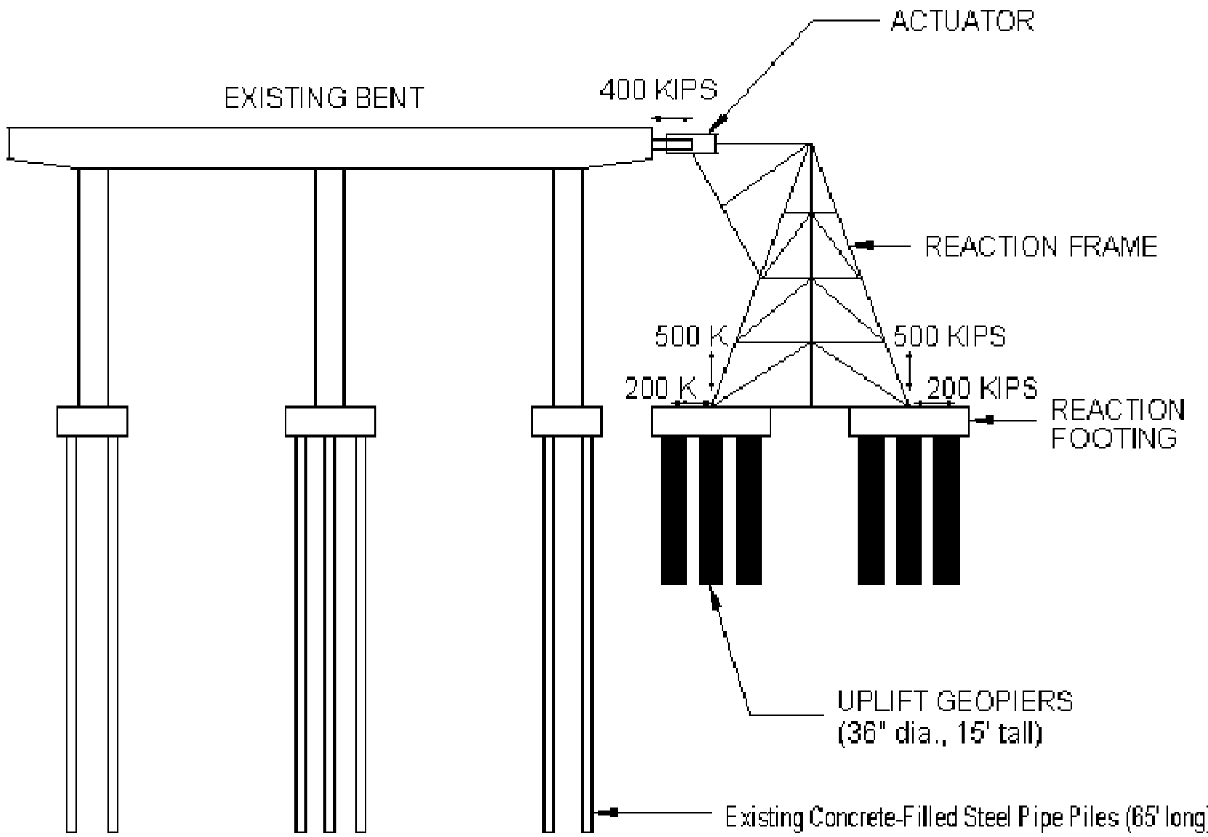

FIGURE 5.
Schematic Representation of Setup for Lateral Load Test on Bridge Bent These tests

These tests will be coordinated with the structural testing of the bents to be conducted by Drs. Chris Pantelides and Lawrence Reaveley of the University of Utah. Three bents will be tested at the I-15 Southbound Bridge over South Temple. One bent (bent 6) already has footings in place to support the reaction frame. These footings were constructed during the testing of the northbound bents 5 and 6 last May and June. These footings are supported by geopiers and the footings and the geopiers are already instrumented. In addition, instrumentation will be placed on the pile caps of the existing bents to monitor vertical and lateral movements during the testing. (Similar instrumentation to monitor movements of the superstructure will be installed and monitored simultaneously by the structural engineers. Combined results from the geotechnical and structural instrumentation of the existing bents and foundations will be used in soil-structure interaction analyses to be discussed subsequently.)

In the testing of the other two bents (bents 4 and 5), one footing will be supported by geopiers and one footing (pile cap) will be supported by piles. Comparison of results for the nearly identical testing conditions and similar subsurface conditions will allow determination of the relative performance of the two types of foundation systems under simulated earthquake loads.

Only structural testing will be conducted on bent 6, with simultaneous monitoring of the structural and geotechnical instrumentation to determine soil-structure interaction. Similar tests were already conducted on these footings during the tests on the northbound bents. Therefore, the primary geotechnical benefit of these tests will be the effect of about one year of aging on the results.

In the tests on bents 4 and 5, geotechnical testing will be conducted first, with structural testing conducted at the completion of the geotechnical tests. Structural and geotechnical instrumentation will be in place prior to any testing and all instrumentation will be monitored during both the geotechnical and structural tests.

The newly constructed pile caps will be constructed, instrumented, and analyzed by BYU under the direction and responsibility of Professor Kyle Rollins.

2. Tests in which cyclic lateral loads only will be applied each set of newly constructed foundations at bents 4 and 5. In each test, the lateral load will be applied by pushing simultaneously on each of the two foundations with either two 150-ton or two 500-ton hydraulic jacks, as shown in Fig. 6. It is anticipated that the lateral load will be applied in ten to twenty increments, with each cycle of load applied over a period of about 15 to 20 seconds.

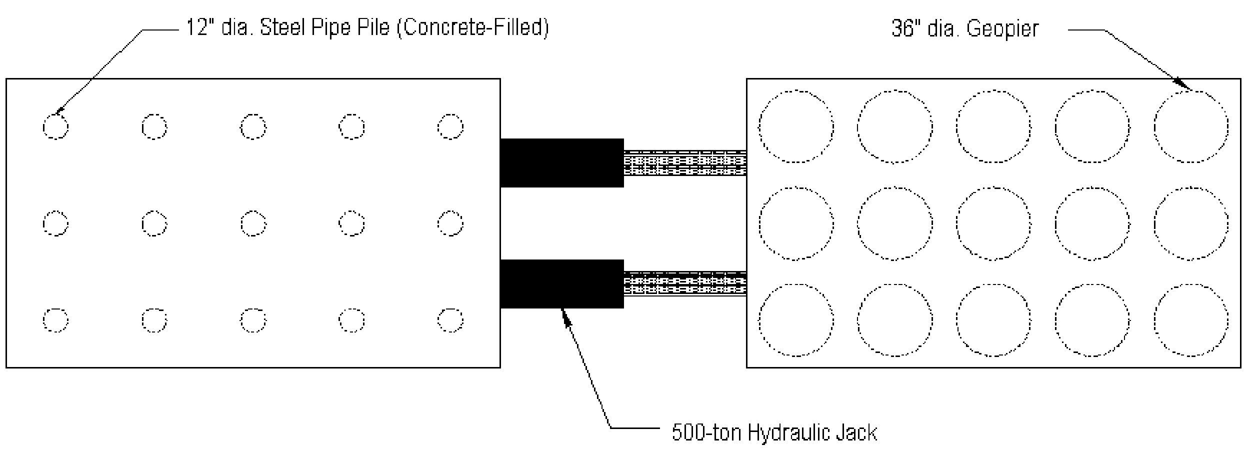

FIGURE 6
Schematic Illustration of Lat. Load Test of 5-Row Pile Group and 5-Row Geopier Group

Results from these tests will allow direct comparison of the technical and cost effectiveness of the two types of foundation systems under nominally identical loading and subsurface conditions, as well as a comparison of the manner in which the lateral loads are carried by the two different systems.

In addition to the comparative tests described in the previous paragraph, tests will also be conducted in which the following parameters will be varied:

- Tests on single geopiers will be conducted. Results from these tests will provide information on the behavior of single geopiers. Furthermore, these baseline results will be used to compare with results from tests on groups of geopiers to determine group effects.

- Spacing of the geopiers. It is critical to know how the spacing influences the group effect and at what spacing can the group effect be neglected (that is, at what spacing does a geopier in a group behave the same under lateral loading as does a single geopier subjected to the same magnitude of lateral load?)

- Tests will be conducted on one footing that was not supported by piles or geopiers. Results from this test will provide baseline information on the lateral resistance of shallow foundations. Comparison of these results with those from the supported footings will enable accurate determination of the additional lateral resistance provided by geopiers for the same size footings and soil conditions. Two tests will be conducted on this shallow footing: one test with no backfill (footing on the ground surface), and one test with backfill to the top of the footing. Comparison of results from these two tests will enable determination of the proportion of resistance provided by sliding along the base and by passive lateral resistance in embedded shallow foundations.

3. After all field tests are completed, the soil surrounding the pile caps for the existing southbound bridge bents, and the reaction frame footings supported by geopiers will be excavated. An investigation will then be conducted to determine the extent of damage (if any) caused by the testing to the bent pile caps and the reaction frame pile caps and piles, and the reaction frame footings and geopiers. This investigation will be used to assess the ability of pile and geopier foundations to survive earthquakes.

   The data obtained from all full-scale field tests will be reduced and analyzed for reasonableness and completeness. Data will be graphed in appropriate ways so that the results can be properly analyzed.

Instrumentation

It is anticipated that the following instrumentation will be used in the geopier foundations supporting the reaction frame, and the existing pile caps, during all testing:

- Four vertical and three horizontal displacement transducers will be used to monitor the movements of each bent pile cap (three existing bent caps) and the reaction frame footing supported by geopiers during the pushover tests.

- Thirteen pressure plates will be used to measure total stress in each geopier foundation system. Four pressure plates will be located along the interface of the bottom of the footing and the native (matrix) soil to measure induced bearing stress on the matrix soil. Five pressure plates will be located along the interface of the bottom of the footing and the top of the geopiers to measured induced vertical stress on the geopiers. Four pressure plates will be located within one geopier at depth intervals of 3 ft to measure the distribution of induced vertical stress within the geopier.

- Nine push-in-cells will be used to measure induced horizontal stresses. Three will be located at various depths within the matrix soil between geopiers. Three will be located at various depths adjacent to a pile in one of the bent pile caps.

- Six piezometers will be located at various points on the site. Three piezometers will be located at general points around the site to give the overall water pressure and groundwater table profiles. The other three piezometers will be located adjacent to the reaction frame and existing bent foundations.

- Strain gages will be attached at the following locations

  - Approximately fifty strain gages will be attached on the reaction frame to all members coming into the bearing support on the footings and pile caps. These strain gages are need to determine the magnitude of the vertical and lateral forces as well as bending moments produced on the pile cap and footing.

  - Strain gages will be attached to selected Dywidag bars in the geopiers to measure tensile forces generated by the lateral and uplift loads.

  - Strain gages will be applied to the top and bottom rows of flexural steel in the reaction frame footings supported by geopiers at various distances from the supports (in both horizontal directions). Data from these strain gages will be used to determine bending stresses generated in the flexural steel, which will aid in determining the reasonableness of existing design methods for flexural steel in footings and pile caps.

LABORATORY TESTS

Appropriate laboratory tests will be conducted to supplement the field tests to determine the stress-strain-strength characteristics of the subsurface materials at the site. Results from the laboratory and field tests will be used to determine appropriate constitutive parameters for the numerical analyses, as well as traditional strength and deformation parameters for use in assess the validity of existing methods of design and analysis and in developing new methods of design and analysis.

NUMERICAL AND THEORETICAL ANALYSES

Finite element analyses simulating selected full-scale field tests of each type will be conducted using the stress-strain-strength parameters obtained in the subsurface characterization phase. Several finite element programs are available at the two universities and can be used in these numerical studies. The available programs include SOILSTRUCT, AXISHL, GEOFEAP, and ABAQUS. Results from these numerical analyses will be compared with actual test results to determine the ability of the numerical analyses to predict the experimental results. Additional analyses will be conducted for typical foundation and subsurface conditions not found in the actual tests. These extended numerical analyses will allow the experimental results to be extrapolated to all conditions, not just the particular conditions of any particular test.

The data and results obtained from the full-scale field tests, as well as the results from the numerical analyses, will be compared with existing theories and methods of analysis and design for the response of piles and geopiers to applied lateral, compressive, and uplift loads. The existing theories and methods of analysis will be modified and improved – or new theories or methods will be developed – based on these comparisons.

SOIL-STRUCTURE INTERACTION ANALYSES

The data and results obtained from the instrumentation of the superstructure on the existing bents will be compared with the data and results obtained from the instrumentation of the substructure. From these comparisons, soil-structure interaction analyses will be performed. These analyses will be performed in conjunction and cooperation with the structural portion of this research. Three-dimensional numerical analyses will be conducted using the finite element program ABAQUS, which has the capabilities of modeling the superstructure, substructure, and subsurface materials (including the matrix soil and the geopiers). The results from these analyses will be compared with the results obtained from the structural and geotechnical tests. This phase may well be the most important of all the phases because little work has been done on true soil-structure interaction analyses of full-scale structures, especially regarding the availability of soil-structure interaction data from full-scale tests.

DOCUMENT AND PUBLISH FINDINGS

The findings of this research project will be disseminated through a number of separate reports and publications. These will include interim and final reports to the DEPARTMENT as well as AASHTO technical committee presentations and TRB publications.

STAFFING AND SUBCONTRACTING PLAN

The completion of the research outlined in this working plan will be the responsibility of Professor Evert Lawton from the University of Utah. However, successful completion on this research also depends on the cooperation from and successful completion of the research programs of Professor Kyle Rollins by Brigham Young University and Professors Chris Pantelides and Larry Reaveley from the University of Utah, all of which are being performed at the same site. In addition, the field portion of the study must be closely coordinated with Penhall Company, the demolition subcontractor for the D/B Reconstruction Project.

In addition, subcontractors yet undetermined will be employed to perform geotechnical subsurface investigation, including CPT, SPT, BST, Ko-blade, sampling etc. Also, a steel erection crew will be employed to move the structural reaction frame one time. The Geopier Foundation Companry Inc. will be participating in the study by furnishing in kind equipment and labor for installation of the geopiers as evidenced by the letter of commitment shown in Figures 7a and 7b.

SCHEDULE

According to the latest information available to us regarding the schedule for the I-15 reconstruction, the South Temple northbound bridge will become available for pushover testing in mid-August 1999. The pushover testing is scheduled to occur between mid-August and the end of September 1999 (approximately 6 weeks are available). Preparatory work prior to testing at South Temple, including construction and lateral testing of reaction frame footings, can begin as soon as funding is received. It is possible that this schedule will change but unlikely that it will change more than a few months at most. A chart showing the preliminary scheduling of the primary tasks for this project are shown in Figure 8. This schedule is based on the information available at this time regarding availability of the bridge for pushover testing and assumes that funding will be received by May 1, 1999.

BUDGET SUMMARY

U of U Contract Costs:	
Personnel Direct Costs:	$ 64,478
Equipment, Materials & Other Costs:	$118,866
Subcontracts:	$ 36,000

Subtotal Contract Direct Costs, Equipment Etc. & Subcontracts:	*$219,364*
Indirect U of U Contract Costs:	*$ 14,436*

Subtotal U of U Contract Costs:	*$233,800*
UDOT Direct Costs:	
Personnel Direct Costs:	$ 5,000
Equipment, Materials & Other Costs:	$ 8,000

Subtotal UDOT Direct Costs, Equipment Etc. & Subcontracts:	*$ 13,000*

Total Project Costs:	***$246,800***

GEOPIER™ Foundation Company, INC.
"The Alternative to Deep Foundations"

geopier™

September 21, 1998

Dr. Evert C. Lawton
University of Utah
Civil & Environmental Engineering
122 South Central Campus Dr., Room 104
Salt Lake City, UT 84112-0561

Subject: Geopier Foundation Participation in I-15 Bridge Research

Dear Dr. Lawton:

Thank you for inviting Geopier Foundation Company (GFC) to participate in your proposal titled "RESPONSE, ANALYSIS, AND DESIGN OF PILE FOUNDATIONS, DRILLED SHAFT FOUNDATIONS, AND GEOPIER FOUNDATIONS SUBJECTED TO LATERAL, UPLIFT, AND COMPRESSIVE FORCES". This research is to be conducted in conjunction with structural research on the I-15 reconstruction project. It is our understanding that you are interested in having approximately ten uplift Geopier elements installed to support one footing for the lateral load reaction frame. In addition, approximately fifty to seventy-five Geopier elements would be needed for other full-scale lateral testing. During structural testing of the bridge bents and subsequent separate testing of other footings and pile caps, the footings and pile caps -- as well as the Geopier elements, piles, and drilled shafts - would be instrumented to obtain meaningful data from these full-scale tests. The data and results would then be analyzed to provide an improved understanding of the behavior of pile foundation systems, drilled shaft foundation systems, and Geopier foundation systems under lateral, compressive, and uplift loads.

GFC would be pleased to participate in this research if the appropriate funding is obtained from the other sources (UDOT/FHWA, NSF, etc.). GFC's contribution to this research would consist of (a) mobilizing and demobilizing to and from the site (including personnel, drilling equipment and tamper), and (b) installing approximately 60 to 85 Geopier elements (estimated to be 36 inch diameter by 15 ft long, including uplift anchors). The materials (base course stone, uplift steel including anchor plates, Dywidag bars and nuts, etc.) and rental equipment (hydraulic excavator, backhoe, etc.) needed to construct the Geopier foundations will be provided by funding from other sources. The estimated value of GFC's contributions to this project is $40,000. In addition, we would require that GFC have access to all data obtained in this project related to instrumentation of the Geopier foundations and the footings being supported by Geopier elements, and that GFC have unrestricted use of those data.

11437 East Aster Drive • Scottsdale, AZ 85260
PHONE: (602) 657-3710 FAX: (602) 657-0720

Figure 7a. Geopier Foundation Company Letter, Page 1

We look forward to working with you on this project should appropriate funding be obtained from UDOT/FHWA and NSF. Should you or any other parties involved in the research need to contact me, I can be reached by telephone at (602) 657-0715.

Sincerely,

Geopier™ Foundation Company, Inc.

Nathaniel S. Fox, P.E., Ph.D.
President

Figure 7b. Geopier Foundation Company Letter, Page 2

81F15023 – Lateral Load Field Tests on Pile Groups, Phase 3

Funding Source:	FHWA Research (TEA-21 FY 1999)		$ 220,240
	State Match (TEA-21 FY 1999)		$ 55,060
	State Pooled Funds		$ 158,000
		*Total Cost Estimate	$ 433,300

Principal Investigator: Kyle Rollins, Brigham Young University

Research Project Manager: Steve Bartlett

*Based on actual projected amounts for Research Division personnel and other costs. Matching amounts from other agencies are based on information provided by others and may not include all costs.

PROBLEM DEFINITION

The lateral load capacity of pile foundations is critically important in the design of buildings and highway structures which may be subjected to earthquake motions. Although fairly reliable methods have been developed for predicting the lateral capacity of single piles under static loads, there is very little information to guide engineers in the design of closely spaced pile groups (i.e. spacings less than about 6 pile diameters) particularly under dynamic loads. Because of the high cost and logistical difficulty of conducting lateral load tests on pile groups, only a few full-scale load test results are available that show the distribution of load within a pile group (Brown et al, 1987; Brown et al, 1988; Meimon et al, 1986; Rollins et al, 1998; Ruesta and Townsend, 1997). These tests have all involved static or quasi-static loadings.

Nevertheless, the data from these limited field tests indicate that piles in groups will undergo significantly more displacement and higher bending moments for a given load per pile than will a single isolated pile (Brown et al, 1987; Brown et al, 1988; Meimon et al, 1986; Rollins et al, 1998; Ruesta and Townsend, 1997). The tendency for a pile in a trailing row to exhibit less lateral resistance because of the pile in front of it is commonly referred to as "shadowing". This shadowing effect becomes less significant as the spacing between piles increases. One method of accounting for the shadowing or group reduction effects is to reduce the single pile p-y (horizontal soil resistance vs displacement) curve using p-multipliers.

Because of the dearth of experimental data, computer programs for pile groups have not been thoroughly validated and empirical methods are extremely restricted in their application. As a result, engineers are forced to design pile groups in a very conservative manner to deal with the uncertainty. Although numerical and centrifuge models can provide some guidance regarding these issues, a reasonable number of full-scale load tests are necessary to verify these models and provide ground truth information.

Over the past two years, Prof. Rollins and his students at BYU have conducted a series of static and dynamic lateral load tests on a full-scale pile group at the Salt Lake International Airport (Rollins et al, 1998, Peterson and Rollins, 1996). The piles were 12 in. diameter steel pipe piles driven to a depth of approximately 30 ft in a soil profile consisting of soft to medium clay. The piles were driven in a 3 x 3 pattern with a nominal spacing of 3 pile diameters center to center. Static loads were applied in one direction with conventional hydraulic jacks while dynamic loads were applied in the opposite direction with a Statnamic loading device. The Statnamic device produced loads of up to 300 tons with peak accelerations between 0.5 and 2.0 g and durations of about 300 msec. These parameters are similar to what might be expected for an earthquake loading. The load in each of the nine piles was measured during both loadings so that the distribution of loading in the pile group could be determined. Tests were also performed with a pile cap to create a fixed-head boundary condition.

As a result of the lateral load tests at the Salt Lake City Airport, significant insight has been provided regarding group reduction factors (p-multipliers), large-strain dynamic resistance, and accuracy of several computer analysis methods (Peterson and Rollins, 1996; Weaver and Rollins, 1997; Sparks and Rollins, 1997). There are, however, several unresolved issues that need to be explored with supplemental full-scale load testing.

The first unresolved issue involves the effect of pile spacing on group effects. Almost all of the available full-scale pile group tests where load distribution was measured, including the Utah tests, involve pile groups spaced at three pile diameters center to center. The p-multipliers obtained from full-scale group load tests are significantly lower than those obtained from model tests. Design charts are needed to show the p-multiplier as a function of pile spacing based on full-scale tests.

A second unresolved issue involves the selection of appropriate p-multipliers for large pile groups. In fact, some people question the validity of the p-multiplier concept for larger pile groups. Four of the five available full-scale pile group tests have been performed on groups with only two or three rows. The results from these tests generally show that the p-multiplier decreases from the front row to the back row although there was some increase in the p-multiplier for the back row in the Utah tests. It is unclear at this point whether the p-multiplier measured for the third row in a group is appropriate for subsequent rows in a large pile group or whether the p-multipliers will continue to gradually decrease with each additional trailing row. Tests on larger groups are necessary to answer this question.

Third, there is presently significant uncertainty about the importance of group effects in earthquake events. For example ATC-32 suggests that "group effects can be neglected for earthquake loading at three-diameter center–to-center spacing or higher" because "for softer soils, cyclic loading tends to remold a zone immediately around the pile, with the weakened soil becoming less effective in transferring induced stresses to the neighboring piles." This issue will continue to be unresolved unless cyclic full-scale static and dynamic load tests are performed in softer silts and clays. These tests would make it possible to evaluate the effects of remolding and gapping on the p-multipliers in these materials and determine if p-multipliers really should be neglected.

Fourth, some state DOTs, such as Caltrans, are moving to the use of larger diameter pile foundations (24 to 36 inch) to resist large lateral loads. Some testing on large diameter drilled shafts suggests that group effects will be less pronounced for stiffer pile foundations in comparison to 10 to 12 inch diameter pile groups which have been tested in the past. Additional testing of large diameter pile groups will help resolve this question.

Finally, the lateral Statnamic testing previously conducted on the pile group at the Salt Lake Airport indicated that the dynamic resistance was significantly higher than the static resistance. The increased resistance was determined to be primarily due to damping, however this testing involved only a few load cycles. Damping may decrease significantly as gaps develop behind the pile with increased number of cycles. Statnamic testing, conducted after various numbers of cycles have taken place, would provide an indication of the effect of gapping on the dynamic capacity.

RESEARCH OBJECTIVES

The proposed driven pile research study has the following objectives:

1. Evaluate the effect of pile spacing on measured p-multipliers and develop design curve for p-multipliers as a function of pile spacing.
2. Determine the validity of the p-multiplier concept for a larger (5-row) pile group and determine if p-multiplier values remain constant beyond the third row.
3. Determine the effect of cyclic loading and gap formation in clays on the measured group effects and p-multipliers.
4. Examine the effect of cyclic loading and gap formation in clays on the measured dynamic resistance.
5. Evaluate the effect of pile diameter and stiffness on p-multiplier values for pile groups.
6. Evaluate the effect of uplift and compression on the lateral resistance of pile groups.
7. Provide a well-documented case history for use in evaluating and calibrating computer and physical models.

WORK PLAN

The work tasks described below will be performed in conjunction with geopier research and structural bent testing being performed at the South Temple site. Since reaction foundations must be provided for the structural testing, these new foundations can be instrumented and tested independently so that the value of the foundations is doubled. In addition, the geopier foundations can serve as reactions for the pile groups and provide a direct comparison of the load carrying ability of the two systems.

It is expected that the objectives of this study can be accomplished by the following work tasks:

(1) Site characterization;

(2) Cyclic lateral load testing of single piles;
(3) Cyclic lateral load testing of 5-row 12" pile group at 3 diameter spacing;
(4) Cyclic loading testing of a 5-row 12" Pile group at 4 diameter spacing;
(5) Cyclic load testing of 3-row 12" pile group at 6 diameter spacing;
(6) Cyclic load testing of a 3-row 24" pile group at 3 diameter spacing;
(7) Cyclic load testing of existing structural bents and foundations**;**
(8) Data reduction and analysis of test results; and,
(9) Report preparation and dissemination of results.

A description of work associated with each task is provided below:

1. Site Characterization

Proper characterization of the subsurface materials are necessary to ensure that the foundation support systems are designed properly, the results from the full-scale field tests are interpreted correctly, and the numerical and theoretical analyses extending these results to other conditions are successful. The characterization of the subsurface materials in this research program will be accomplished by the following approach:

Previous testing by Wasatch Constructors and the University of Utah has already provided a substantial amount of information at bents near the test area for the piles. This information, consisting of cone penetration testing, shear wave velocity testing, and shear strength testing is valuable and will be utilized in this study. However, it will still be necessary to conduct some additional field and laboratory testing at the locations of the new pile foundations to assure consistency of the profile and material characteristics across the site. At least one Standard Penetration Test (SPT) hole, one Cone Penetration Test (CPT) hole, and pressuremeter Test (PMT) hole will be conducted at the location of each newly constructed pile group. Undisturbed samples and disturbed samples will be obtained for laboratory testing. Laboratory testing will include one-dimensional consolidation, unconfined compression (UU), and triaxial CU with pore pressure measurements. Results from these tests will be used to determine appropriate stress-strain-strength parameters for the numerical and theoretical analyses to be conducted after the field tests and data reduction have been performed.

2. Cyclic load testing of a single piles

Initially, cyclic load tests will be performed on two isolated single piles driven to a depth of 40 feet in undisturbed soil adjacent to the geopier pile cap at bent 4. These tests are necessary to provide a comparison to the behavior of the pile groups. One pile will consist of a closed-end 12.75" (0.5" wall) dia. pipe filled with concrete while the other will be an open-end 24" dia. (5/8" wall) steel pipe. Strain gages will be placed on opposite faces pile at 10 depth levels and an inclinometer pipe will be placed in each pile. The pile will be tested at least 30 days after driving so that excess pore pressure will have dissipated. The pile cap over the Geopiers will provide the reaction for the testing.

Load will be applied in approximately 10 increments with a hydraulic jack. Applied load will be measured with a load cell and pile head deflection and rotation will be measured with LVDTs. A data acquisition system will be used to record the data. For each load increment, the load will initially be held constant for a period of 5 minutes after which an inclinometer sounding will be performed. Thereafter, 24 additional load cycles will be applied using a load-control approach and pile head deflection and rotation will be measured. A total of 25 load cycles would simulate the number of cycles produced by a M7.5+ earthquake event.

Each load cycle will be applied over a period of about 15 to 20 seconds. The last load application will be held constant for 5 minutes and a final inclinometer sounding will be made. The inclinometer soundings will make it possible to plot curves of deflection versus depth for before and after cycling. The strain gages will make it possible to plot the bending moment versus depth in each row of the pile group for each load cycle.

3. Cyclic load testing of a 5-row 12" dia. pile group at 3 diameter spacing.

Cyclic load testing will also be performed on a 15 pile group driven in a 3 x 5 arrangement at bent 4 as shown in Figure 9. The piles will be spaced at 3 pile diameters (36 in) center to center and driven to a depth of 40 ft. The load will be applied to the load frame using two 150-ton hydraulic jacks having a stroke of 13 inches and measured with a load cells. This will allow an average load of 40 kips per pile to be applied. A load frame has been designed to provide the same displacement at each pile location and be essentially rigid in comparison with the stiffness of the piles. Most of the members for the frame are available from previous testing, however, some additional parts will need to be purchased

Each pile will be attached to the load frame by a tie-rod with a moment free connection. Strain gages attached to each tie-rod will provide a continuous readout of the load carried by each individual pile during the test. Nine of the instrumented tie-rods are still available from previous pile group testing, however, six additional tie-rods will need to be manufactured. The tie-rod instrumentation will make it possible to accurately determine the load distribution in the pile group.

Pile head deflection will be measured at six locations using LVDT's attached to an independent reference frame to ensure that the group is moving uniformly. In addition, pile head rotation will be measured at three locations. Strain gages will be placed on opposite faces of one pile in each row at 14 depth levels and an inclinometer pipe will be placed at the center of this pile. These instrumented piles are being used for testing in San Francisco and will be shipped back to Utah for these tests. The same sequence of loading described for the single pile test will be employed for the pile group test.

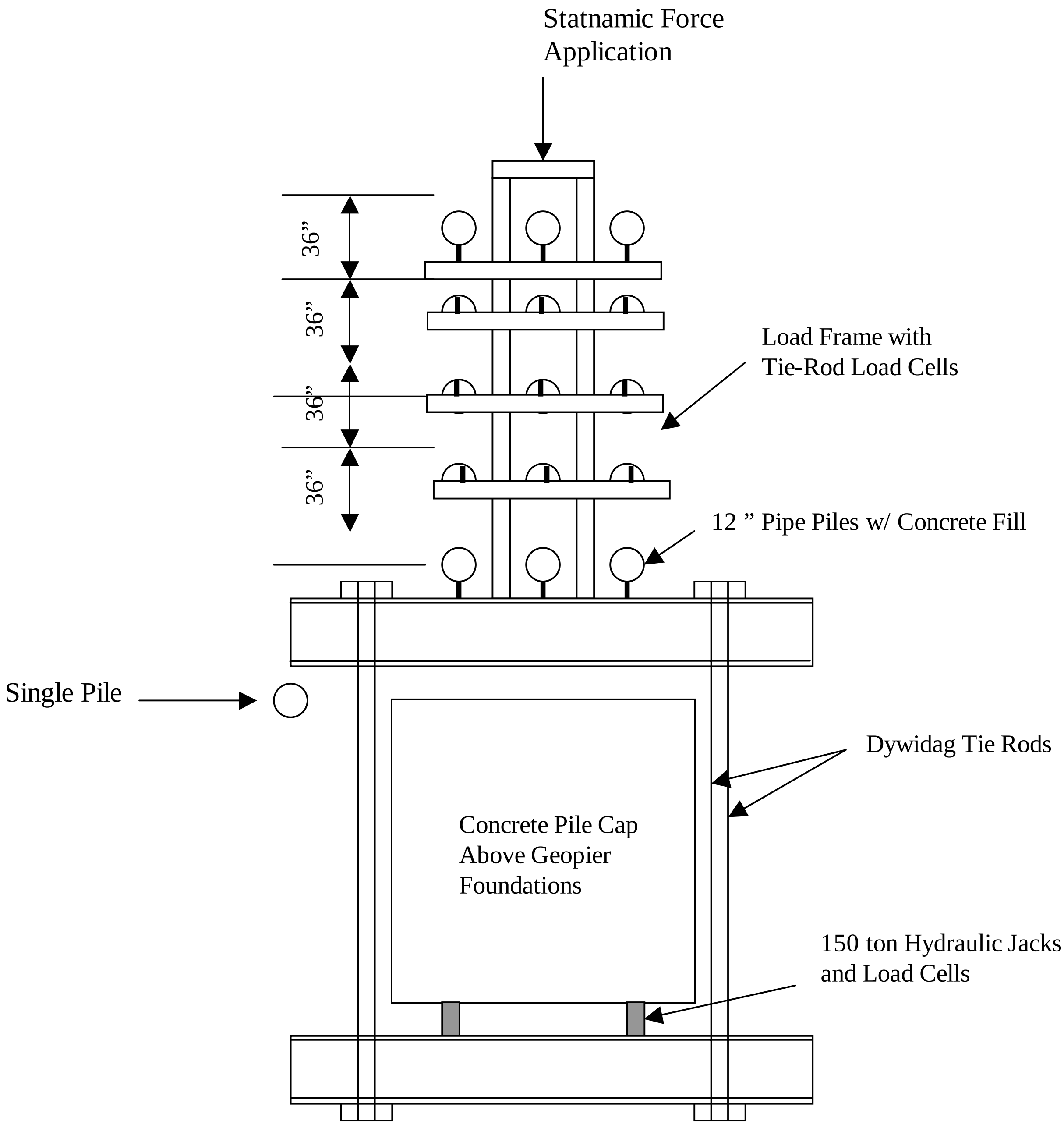

Figure 9
Schematic plan view diagram of load test set-up to evaluate group effects at 3 pile diameter center-to-center spacing at Bent 4 at South Temple.

In addition to the static loading, a Statnamic device will be used to provide a dynamic loading at 3 load levels (30%, 70% and 100%). The Statnamic load application will be conducted at the end of the static cyclic loading at the prescribed load levels. This testing would provide three benefits. First, it will provide a comparison between the static and dynamic capacity after gap formation and cyclic loading of the soil. Second, it will provide a comparison of load distribution under dynamic loading. Third, the test results can be used to back-calculate damping coefficients for dynamically loaded piles.

4. Cyclic load testing of 5-row 12" dia. pile group at 4 diameter spacing.

Cyclic load testing will also be performed on a 15 pile group driven in a 3 x 5 arrangement at Bent 5. The arrangement will be identical to that shown in Figure 9, however, the piles will be spaced at 4 pile diameters (48 in) center to center and driven to a depth of 40 ft. The testing program and instrumentation would be essentially the same as that for the previous set of tests except the spacing would be increased and dynamic testing would not be performed.

5. Cyclic load testing of 3-row 12" dia. pile group at 6 diameter spacing.

Upon completion of the testing of the 5-row pile groups, the load frame will be rearranged so that a group consisting of 9 piles (3 x 3 arrangement) can be loaded at Bent 4 as shown in Figure 10. This test arrangement will make it possible to evaluate group effects for piles spaced at 6 diameters on centers in the direction of loading. Once again, tie-rod load cells will be used to independently measure the load carried by each pile and pile head deflection and rotation will be measured with LVDTs. Strain gages will be placed at 8 levels and inclinometer readings will also be taken. Generally, the same loading sequence will be employed as described previously for the other tests except that dynamic testing will not be performed.

6. Cyclic load testing of 3-row 24" dia. pile group at 3 diameter spacing.

Cyclic load testing will also be performed on a 9 pile group driven in a 3 x 3 arrangement at bent 5. The piles will be spaced at 3 pile diameters (36 in) center to center and driven to a depth of 40 ft. The piles will be 24" dia. steel pipe driven open-ended. The load will be applied to the load frame using two 500-ton hydraulic jacks having a stroke of 13 inches and measured with a load cells. This will allow an average load of over 200 kips per pile to be applied. Some of the members for the frame are available from previous testing, however, additional parts will need to be purchased. In addition, pinned-connection tie-rod load cells with higher capacities will have to be manufactured.

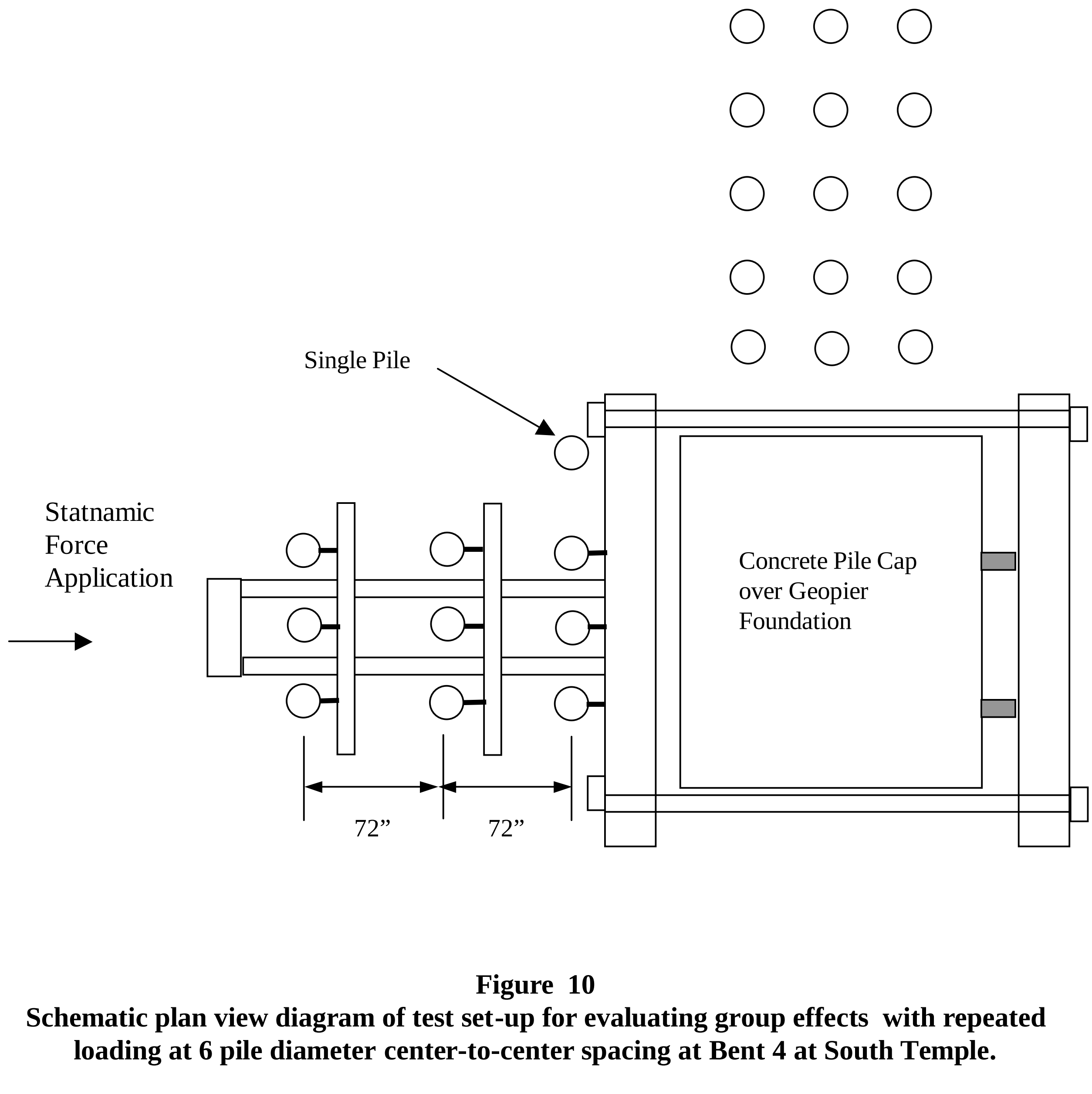

Figure 10
Schematic plan view diagram of test set-up for evaluating group effects with repeated loading at 6 pile diameter center-to-center spacing at Bent 4 at South Temple.

One pile in each row will be instrumented with two strain gages at 10 depth levels. A static load test will be performed in accordance with the general procedure described previously for the 12 inch diameter piles. In addition, a series of statnamic load tests will be performed.

7. Cyclic load testing of existing structural bents and foundations

During the bent tests, four newly constructed and four existing reinforced concrete foundations will be subjected to simulated cyclic earthquake loads consisting of a horizontal force (alternating in direction), a vertical force (alternating compression and uplift), and a moment (alternating direction) generated by the horizontal force acting on the top of the footing or pile cap. The footings or pile caps in these tests will be supported by concrete-filled steel pipe piles and geopiers. The footings will support a structural steel frame and a hydraulic actuator that will alternately push and pull horizontally on the cap of existing I-15 bridge bents (see Figure 11) prior to their demolition.

These tests will be coordinated with the structural testing of the bents to be conducted by Drs. Chris Pantelides and Lawrence Reaveley of the University of Utah. It is anticipated that three bents will be tested at the I-15 Southbound Bridge over South Temple. Bent 6 already has footings which will serve as reactions for the testing. These footings are supported by geopiers and the footings and the geopiers are already instrumented. In addition, instrumentation will be placed on the pile caps of the existing bents to monitor vertical and lateral movements during the testing. (Similar instrumentation to monitor movements of the superstructure will be installed and monitored simultaneously by the structural engineers. Combined results from the geotechnical and structural instrumentation of the existing bents and foundations will be used in soil-structure interaction analyses to be discussed subsequently.

In the testing of the other two bents (tentatively bents 4 and 5 at South Temple), two new footings or pile caps will be constructed at each bent. At each new bent, one footing will be supported by pile foundations while the second will be supported by geopiers. Comparison of results for the nearly identical testing conditions and similar subsurface conditions will allow determination of the relative performance of the two types of foundation systems under simulated earthquake loads. For the tests on bent 5 structural testing will be performed prior to geotechnical testing. However, for bents 4 and 5, geotechnical testing will be conducted first, and structural testing conducted at the completion of the geotechnical tests. Structural and geotechnical instrumentation will be in place prior to any testing and all instrumentation will be monitored during the tests.

8. Data reduction and analysis of test results.

The results from the testing program will be reduced and at least the following graphs will be prepared:

- Average pile head load versus deflection curves for the first and last cycle for the single pile and pile groups.
- Maximum bending moment versus applied load as a function of load cycle for the single pile and pile groups.
- Bending moment versus depth curves for each load cycle at each load increment for the single pile and the pile groups.
- Lateral deflection versus depth curves for the first and last cycle at each load increment for the single pile and the pile groups.
- Normalized load versus deflection curves to show average load carried by piles in each row relative to that carried by a single pile.
- Reduction in load carrying capacity as a function of the number of cycles
- Ratio of statnamic to static load resistance as a function of the load level and gapping.
- Damping resistance as a function of pile head displacement.

Based on the results of the testing it will also be possible to determine appropriate p-multipliers by either back-calculation with existing computer models or by computing p-y curves from the bending moment versus depth curves. The results for the 5-row pile group will make it possible to obtain p-multipliers as a function of row position. The results from both the 5- row and 3-row pile groups will make it possible to obtain p-multipliers as a function of center to center pile spacing. The results from the cyclic testing on both pile groups will also make it possible to provide p-multipliers as a function of number of cycles.

Finally, studies will be conducted to evaluate the ability of computer programs for analyzing laterally loaded piles and pile groups to match the behavior observed in the testing. We anticipate using the programs LPILE/GROUP (Reese et al, 1996) and FLPIER (Florida Dept. of Trans., 1996). The GROUP program uses the finite difference method and is widely used in practice. The FLPIER program uses the finite element method and was developed by McVay and his co-workers at the Univ. of Florida. This program is distributed by the Florida DOT at minimal cost and will likely see increased use as a result of FHWA support. Both of these programs employ the p-y concept and allow the user to define p-multipliers. These programs were found to provide reasonable estimates of the lateral load behavior of the pile group in the previous testing program. Validation studies of this type are crucial in providing designers and researchers with "ground truth" information regarding the ability of computer programs to model real conditions.

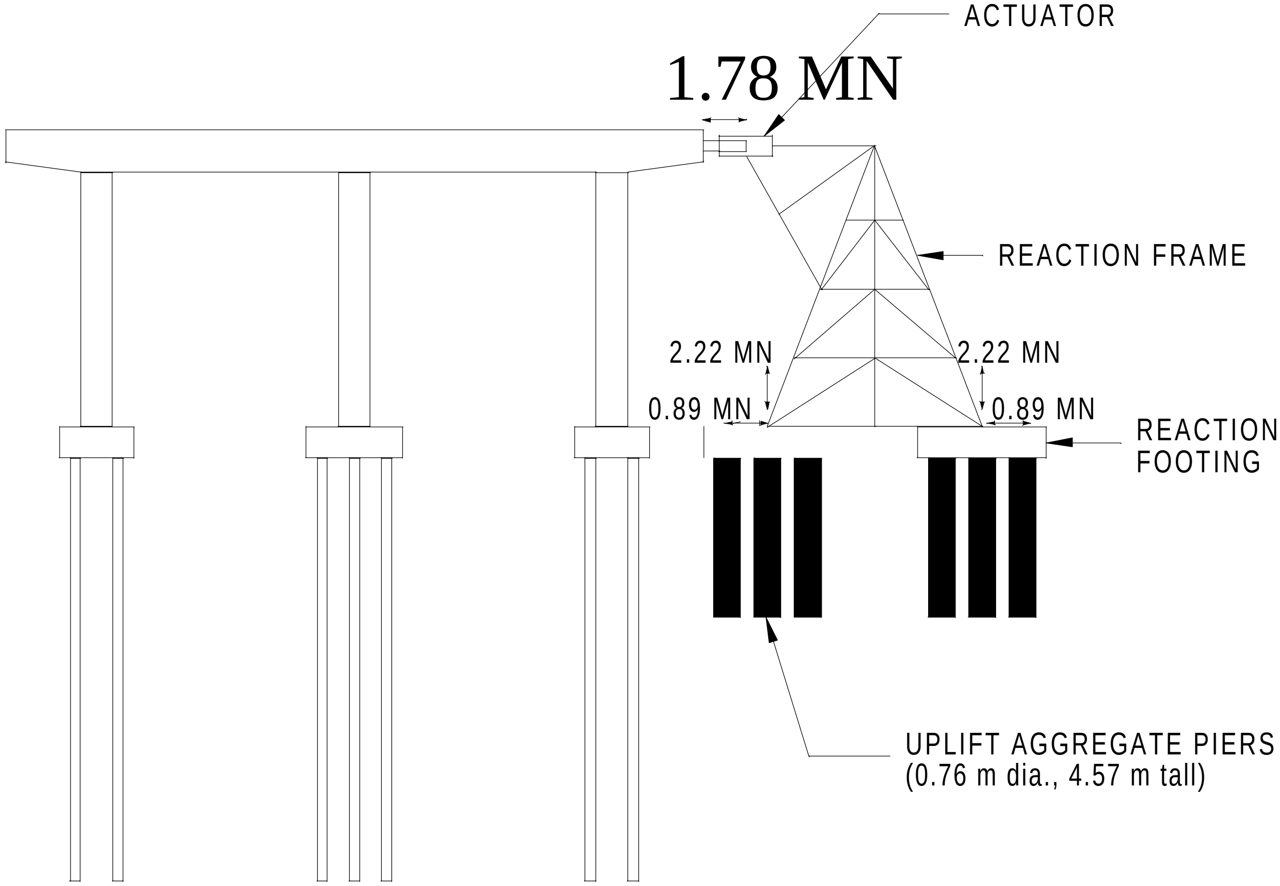

Figure 11
Schematic representation of setup for lateral load test on bridge bent

9. Report preparation and dissemination of results.

A final report will be prepared at the conclusion of this study that will be provided to the sponsors. Two page quarterly reports will also be prepared to summarize the progress of the work. The final report will provide a detailed summary of the characteristics of the soil profile based on field and laboratory testing along with details regarding the pile properties. The test procedures employed in the testing will be described and the results presented. Conclusions based on the testing program will also be presented. An executive summary will briefly summarize the investigation and highlight test results that can be implemented in design procedures.

The report and technical papers will be prepared for publication in appropriate engineering journals and conferences. We anticipate that presentations will be made at the TRB meeting and the

AASHTO Bridge Committee meetings. In addition, digital results from this testing program will be distributed on CD's so that interested researchers desiring to use other computer models will have a detailed record of all test results.

STAFFING AND SUBCONTRACTING PLAN

The completion of the research outlined in this working plan will be the responsibility of Professor Kyle Rollins of Brigham Young University. However, successful completion of this research also depends on the cooperation from and successful completion of the research programs of Professor Evert Lawton, Chris Pantelides and Larry Reaveley from the University of Utah. Also, the field portion of the study must be closely coordinated closely with Penhall Company, the demolition subcontractor for the D/B Reconstruction Project.

In addition, subcontractors yet undetermined will be employed to perform geotechnical subsurface investigation, including CPT, SPT, BST, PMT, sampling etc. Also, a steel erection crew will be employed to move the structural reaction frame one time. Piles and pile driving will be performed by Build, Inc. Dynamic testing will be performed by Applied Foundation Testing. High speed data acquisition systems will be rented from Auburn University or FHWA.

SCHEDULE

According to the latest information available regarding the schedule for the I-15 reconstruction, the South Temple northbound bridge will become available for pushover testing in mid-August 1999. The pushover testing is scheduled to occur between mid-August and the end of September 1999 (approximately 6 weeks are available). Preparatory work prior to testing at South Temple, including construction and lateral testing of reaction frame footings, can begin as soon as funding is received. It is possible that this schedule will change but unlikely that it will change more than a few months at most. A chart showing the preliminary scheduling of the primary tasks for this project are shown in Figure 12. This schedule is based on the information available at this time regarding availability of the bridge for pushover testing and assumes that funding will be received by May 1, 1999.

BUDGET SUMMARY

BYU Contract Costs:

Personnel Direct Costs:	$116,343
Equipment, Materials & Other Costs:	$124,998
Subcontracts:	$135,750

Subtotal Contract Direct Costs, Equipment Etc. & Subcontracts:	*$377,091*
Indirect BYU Contract Costs:	*$ 37,709*

Subtotal BYU Contract Costs: *$414,800*

UDOT Direct Costs:

Personnel Direct Costs: $ 5,000

Equipment, Materials & Other Costs: $ 13,500

Subtotal UDOT Direct Costs, Equipment Etc. & Subcontracts: *$ 18,500*

Total Project Costs: ***$433,300***

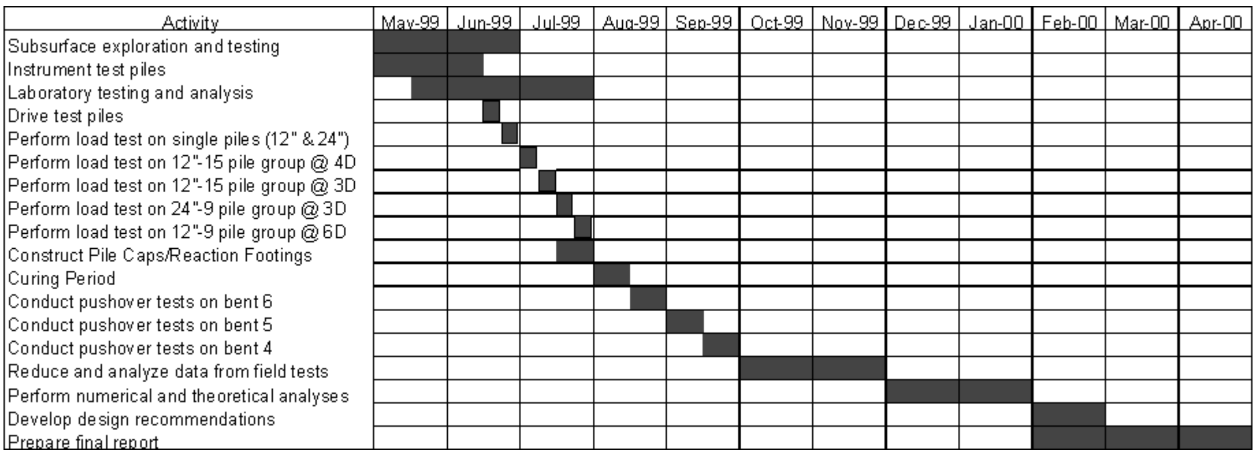

Figure 12
Tentative schedule of activities based on May 1, 1999 start date

81F15024 – Field Testing and Computer Modeling of a Curved Steel Girder Bridge, Phase 1

Funding Source:	FHWA Research (TEA-21 FY 1999)		$ 186,720
	State Match (TEA-21 FY 1999)		$ 46,680
	State Construction		$ 24,000
		*Total Cost Estimate	$ 257,400

Principal Investigator: Kevin Womack, Utah State University

Research Project Manager: Sam Sherman, UDOT

*Based on actual projected amounts for Research Division personnel and other costs. Matching amounts from other agencies are based on information provided by others and may not include all costs.

PROBLEM DEFINITION

The American Association of Highway and Transportation Officials (AASHTO) are beginning the process of developing design equations for the Load and Resistance Factor Design of curved steel bridge girders. To support this effort research engineers of the Federal Highway Administration, at the Turner-Fairbanks testing facility in McLean, Virginia, are testing full scale curved steel girders to develop data for the calibration of computer models and the verification of the AASHTO design equations. When these research engineers were informed that there is a three span, continuous curved steel girder bridge on the I-15 corridor which is to be demolished in late summer of 1999 they immediately expressed an interest in testing this bridge to provide additional data for the verification of computer models and design equations.

OBJECTIVES

The main objectives of this research are to provide data on the response of an existing curved steel girder bridge, in three different condition states, when subjected to static and dynamic loads. And to calibrate, in combination with the data from the Turner-Fairbanks tests, detailed and sophisticated computer models for curved steel girder bridges; and help verify, through the field testing and computer models, design equations developed for curved steel girders by AASHTO.

POTENTIAL BENEFITS

Potential benefits as a result of this study include:

- Understanding the effect of boundary conditions;
- Verifying AASHTO LRFD design equations;

- Elimination of unnecessary conservative design;
- Corroboration of Finite Element Model; and,
- Better analytical tools.

MAJOR TASKS

The bridge to be tested is Br. No. 302B located at the I-15 and I-215 interchange in Salt Lake City, Utah. It has been decommissioned and is scheduled for demolition late this summer. Formerly, the bridge was used as a connector for northbound I-15 traffic to reach westbound I-215. This research will be conducted over the next three years with each year being a phase of the project. The nine major tasks of this research, and the phases they fall in, are listed as bulleted items below.

Note that only funding for Phase I of the study (Tasks 1 through 4) is included in this specific research program. Other funding sources will be sought to complete Phases II and III. However, the work tasks for these additional phases (Tasks 5 through 9) have been shown for completeness.

- Develop simple, preliminary computer models of the bridge (Phase I);
- Collect data on the behavior of the bridge, in three condition states, when subjected to static and dynamic loads (Phase I);
- Analyze the test data to determine the behavior of the bridge under static (Phase 1) and dynamic (Phase 2) loads;
- Produce a draft and final Phase 1 technical report on the field static tests and analysis (Phase I);
- Develop very detailed, sophisticated computer models for the analysis and prediction of behavior for curved steel girder bridges (Phase II);
- Corroborate the computer models utilizing data from the I-15 field test and the Turner-Fairbanks testing (Phase II);
- Produce a draft and final Phase 2 technical report on the development and verification of the computer models (Phase II);
- Verify the AASHTO equations for LRFD procedures to design curved steel girders (Phase III); and,
- Produce a draft and final technical report on verification of AASHTO design equations (Phase III).

Task 1 - Preliminary Computer Models (Phase I Task)

Prior to the field testing a simple computer model will be developed to help determine the best positions for instrument placement and provide preliminary indications of the bridges behavior when placed under the static and dynamic loads. This model will be developed at USU using SAP 2000.

Task 2 - Conduct Field Testing and Collect Data (Phase I Task)

Both static and dynamic tests will be run on the curved girder bridge at the I-15 and I-215 interchange. The "static" tests will consist of static and crawling truck loads. The static truck loads will be placed one at a time on each of the three bridge spans with the intent of inducing the maximum moment in the span being loaded. The crawling truck loads will consist of moving a tandem of trucks across the bridge at a very slow speed. Each of these "static" tests will be conducted three times to ensure repeatability. The dynamic loads will be transverse and longitudinal in direction and induced by an eccentric mass shaker. A large 500 pound "hammer" will also be used to provide an impulse load to the bridge to induce a dynamic response.

USU researchers will prepare the site for field testing by laying out reference marks, setting up field trailer, installing instrumentation mounts, etc.. Bridge Diagnostics, Inc. (BDI) will conduct the static load tests, under the supervision of FHWA and USU researchers. BDI is the consultant selected by the FHWA to install instrumentation and collect the static test data. Each static test will need to be repeated three times with instruments placed in different locations because of limited amount of instrumentation (maximum 48 channels available) and because of the need to get as much data as possible from the static tests. The placement of instruments over the I-215 freeway for the static tests will require traffic control, provided by UDOT, to close the freeway.

The USU researchers will conduct the dynamic testing. The total response of the bridge due to a sinusoidal forcing (the eccentric mass shaker) will be determined at frequencies up to 20 Hz. Bridge response at higher frequencies will be induced by an impulse load using the 500-pound hammer. The combination of these two dynamic tests will define very well the dynamic characteristics of this bridge.

The intent of the testing is to examine the bridge in three different condition states. One of the most critical aspects of modeling structures is being able to correctly define the boundary conditions. Currently the curved girder bridge has a deck that is continuous into the abutment creating a fixed boundary condition at the ends of the deck. The rocker bearings at the abutments are frozen and most likely damaged due to longitudinal movement of the bridge also creating a potentially fixed condition for the ends of the steel girders. This as-is condition would be the first condition state in which the bridge will be tested. Instrumentation for the static tests will be placed at key locations near the bridge supports to define very well how the supports function.

The second condition state in which the bridge will be tested is with the deck cut away from the abutment, creating a free boundary condition at the ends of the deck. The third, and last, condition state in which we propose to test the bridge is with the girder end bearings being replaced with elastomeric pads and the intermediate supports over the bents being cleaned and greased. Being able to test the bridge in this condition is dependent on the cost of replacing the end bearings and cleaning the intermediate bearings. If there is enough money in the research budget to perform this work the bridge will be tested in this state, if the cost of this work exceeds the amount available in the budget for it then the bridge will not be tested in this sta te.

Testing the bridge in these three condition states will provide valuable information on the boundary conditions of this bridge, which is essential for good modeling, and also how the characteristics and response of the bridge as the support conditions change.

Task 3 - Analyze Test Data (Phase I Task)

Researchers at both the FHWA and USU will analyze the test data from the static tests. Strains, and subsequently stresses, at key positions along the bridge will be determined from the static test and crawl test. Influence diagrams will also be developed from the crawl tests.

Task 4- Phase I Technical Report (Phase I Task)

A draft and final technical report based on the work performed by the USU researchers will be written according to the outline described in Attachment B, Article B9 to this contract. This report will contain important conclusions on the behavior of curved steel girders based on the results of the I-15 field static testing and subsequent analysis.

The draft report is to be circulated to the Technical Advisory Committee for review and comments. Additionally, a presentation is to be made to the TAC after the report has been circulated. The report will then be finalized by the CONTRACTOR and published by UDOT. Also, a presentation will be given to AASHTO technical committees. In addition, technical papers will be submitted to TRB and SPIE for publication and presentation.

Task 5 - Computer Modeling (Phase II Task)

Detailed finite element computer models for this bridge will be developed at both the FHWA and USU. These three-dimensional models will utilize both beam and shell elements with such detail that web and flange behavior for the steel girders will be well defined. It will be essential that the models be sufficiently detailed to determine precisely the strains at the points on the bridge where strain gages were placed during the field testing. The boundary conditions will also have to be precisely modeled based on data from the field testing.

The data from the dynamic testing will be analyzed by the USU researchers. Critical dynamic characteristics of the bridge, natural frequencies, mode shapes and damping, will be determined from these tests.

Task 6 - Corroborate Computer Models (Phase II Task)

The intent of these models is to be able to model any type of curved steel girder bridge. If models of the bridge to be tested on I-15 and the girders being tested at Turner-Fairbanks are developed and confirmed by the test data to a point of high confidence, then these models can be altered to determine the characteristics of other curved steel girder bridges with different geometries, reducing the need for further laboratory and field testing.

Task 7- Phase II Technical Report (Phase II Task)

A draft and final technical report based on the work performed by the USU researchers will be written according to the outline described in Attachment B, Article B9 to this contract. This report will contain important conclusions on the computer modeling of curved steel girders and model verification.

The draft report is to be circulated to the Technical Advisory Committee for review and comments. Additionally, a presentation is to be made to the TAC after the report has been circulated. The report will be published by UDOT.

Task 8 - Verification of AASHTO Design Equations (Phase III Task)

Load and resistance factor design equations developed by AASHTO, potentially in part from the data collected on the I-15 and Turner-Fairbanks tests, will be verified by running a very large number of design scenarios on the computer models developed as part of this project. This will provide the level of confidence needed for AASHTO to seek approval for the curved steel girder design equations developed.

Task 9 – Draft and Final Technical Report (Phase III Task)

A draft and final technical report based on the work performed by the USU researchers will be written according to the outline described in Attachment B, Article B9 to this contract. This report will contain important conclusions on the behavior of curved steel girders based on the results of the I-15 Phase I field testing. The results of the computer model, developed for this bridge during the Phase II activities will be detailed and compared to the actual field testing data. In addition, sample design cases utilizing the AASHTO equations will be compared to computer models to show the behavior of a design based on the AASHTO equations.

REPORTS, MEETINGS AND PRESENTATIONS

Reports - Two (2) types of reports are expected for this contract as follows:

1. *Progress Reports* are to be provided or when submitting for payment in accordance with Attachment B, Article B7- Progress and Progress Reports that describe:
    a) Progress and/or deliverables completed for the quarter
    b) Brief Synopsis of deliverable content
    c) Issues that have to be resolved
    d) Work anticipated for next progress period.
2. *Technical Reports* - A Draft and Final Technical Report is to be prepared that documents findings and results containing the necessary elements described in more detail in Attachment B, ArticleB9. A Draft of the Report is to be circulated for review and comment

with the UDOT Technical Advisory Committee. The Draft and Final Technical Report are to be delivered to the UDOT Project Manager for circulation according to the schedule shown in Section C3- Schedule. In addition, technical papers will be submitted to TRB and SPIE for publication.

Meeting(s) - Approximately three (3) meetings are anticipated requiring long distance travel to for some of the TAC members as follows:

Group	Topic/Outcome
1. Technical Advisory Committee	Confirmation of Testing Plan & Scope of Work
2. Technical Advisory Committee	Review of Interim of Findings and Results
3. Technical Advisory Committee	Review of Draft Technical Report

Presentation(s) - A final presentation & demonstration is expected and will be schedule at the review of the Draft Technical Report of the project and is to be given in Salt Lake City. The location and time of the meetings and final presentations will be determined in cooperation with the Research Project Manager and Principal Investigators. Other presentations will be given to AASHTO, SPIE, and TRB.

IMPLEMENTATION STRATEGY

It is expected that the results from this effort will be used to validate AASHTO equations and provide a correlation between the analytical results derived in the Turner -Fairbanks lab and the field experimental results. Additionally, the results from the field dynamic tests will provide further evidence of the feasibility of using dynamic testing to assess structural conditions. The dynamic test results will compliment the results from the research that Utah State University is conducting on structural conditions using dynamic testing techniques.

STAFFING AND SUBCONTRACTING PLAN

Kevin C. Womack, Ph.D., P.E., Principal Investigator
Marvin W. Halling, Ph.D., P.E., Co-Principal Investigator

This research project is a joint effort between researchers at the Federal Highway Administration (FHWA), lead by Dr. Hamid Ghasemi, and the above researchers from Utah State University (USU). This work plan describes the research to be performed by researchers from both groups; however, the major focus will be on those efforts that are to be made by the USU researchers.

Bridge Diagnostics, Inc. (BDI) will perform the instrumentation and data collection for the field tests. A-Core will perform concrete cutting at the ends along the abutments.

Extensive coordination with UDOT, FHWA, Wasatch Constructors, the Penhall Company and traffic control contractors will be a very high priority.

SCHEDULE

The following schedule is anticipated for Phase I of this study. The duration and elapsed time for the testing may require modification as a result of the schedule changes due to I-15 reconstruction. Close coordination between the UDOT research liaison and the research team is necessary to exchange timely information regarding Wasatch Constructors and associated work.

Task	Project Schedule Phase I	Duration (in weeks)	Time Elapsed* (in weeks)
1	Develop Preliminary Computer Models	4 weeks	4 weeks
2	Conduct Field Testing and Collect Data	12 weeks	16 weeks
3	Analyze Test Data	34 weeks	50 weeks
4	Draft and Final Interim Technical Report	4 weeks	54 weeks

* Project time line begins with the issuanc e of the □Notice to Proceed□

BUDGET SUMMARY (Phase I)

USU Contract Costs:

Personnel Direct Costs:	$ 84,100
Equipment, Materials & Other Costs:	$ 64,300
Subcontracts:	$ 60,400

Subtotal Contract Direct Costs, Equipment Etc. & Subcontracts:	*$208,800*
Indirect USU Contract Costs:	*$ 17,600*

Subtotal USU Contract Costs:	*$226,400*

UDOT Direct Costs:

Personnel Direct Costs:	$ 12,000
Equipment, Materials & Other Costs:	$ 13,000
Subcontracts:	$ 6,000

Subtotal UDOT Direct Costs, Equipment Etc. & Subcontracts:	*$ 31,000*

Total Project Costs:	***$257,400***

81F15025 – Forced Vibration as a NDE Technology, Phase 2

Funding Source:	FHWA Research (TEA-21 FY 1999)		$ 243,360
	State Match (TEA-21 FY 1999)		$ 60,840
		*Total Cost Estimate	$ 304,200

Principal Investigator: Marvin Halling, Utah State University

Research Project Manager: Sam Sherman, UDOT

*Based on actual projected amounts for Research Division personnel and other costs. Matching amounts from other agencies are based on information provided by others and may not include all costs.

PROBLEM DEFINITION

Today's transportation infrastructure is vulnerable to damage and destruction from a variety of threats including, earthquakes, floods, high winds, vehicle impacts, hazardous cargo spills, terrorist attacks and the long term effects of deterioration. Sometimes the extent of damage is readily discernible and sometimes it is hidden from conventional inspection procedures. Often condition assessments for the type of damage described above must be made under crisis or emergency circumstances. Non-destructive evaluation (NDE) includes a large range of technologies that are becoming increasingly important in our desire to learn about the condition of a structure in a non-destructive way and with increased speed and reliability.

Condition assessment of highway bridges is further complicated by the need to determine the extent of strength lost in highly redundant structural systems. Most NDE methodologies are based on detecting the presence of some damage manifestation, such as a crack, tear, deformation, etc. The extent of strength loss must then be inferred from these manifestations, which can be a laborious and complicated process for bridges. What is needed is a NDE methodology that could measure strength loss of bridges directly.

One promising NDE methodology for assessing the extent of strength loss of bridges more directly employs forced vibration analysis. The theory behind forced vibration analysis is based on the relationship between frequency and stiffness. Should a structure be significantly damaged, to the point of causing damage to the structure, the stiffness will be reduced. This change in stiffness will result in a lowering of the natural frequencies of the structure. The mode shapes of the structure and modal damping will also change due to the occurrence of localized damage. If the change in the natural frequencies, mode shapes and damping of a structure are detectable through forced vibration analysis, then forced vibration analysis could be used as a nondestructive damage detection tool. The change in frequency indicates the presence of damage and the change in mode shapes may help to determine the location of the damage. Ambient vibration (Rubin, 1980; Stevenson and Rubin, 1978) as well as forced vibration (Ruhl and Berdahl, 1979) have been performed on off-shore platforms with varying amounts of success. These structures, however, are located in extremely noisy environments.

Recently, there is an even more intense interest in the utilization of modal analysis techniques as a NDE technique. Recent work (Aktan et al., 1997; Salawu and Williams, 1995; and Muhammad, Halling, and Womack, 1999) shows promising results that indicate that with extremely high levels of precision in both the data collection and processing, damage can be detected and located in a structure.

Through the use of an eccentric mass shaker, very large structures may be subjected to harmonic excitations. Typical mass shakers are capable of excitations up to a frequency of 20 Hz with an oscillating force of up to 20,000 pounds. This level of excitation in large structures, such as bridges, results in only small structural displacements that are nondestructive in nature. However, through the use of the mass shaker and accelerometers to record the motion of a structure the natural frequencies and mode shapes of the structure may be determined. This is done by cycling the frequency of the excitation from zero to 20 Hz in small increments and focusing on the frequencies that induce increased responses from the structure (resonance). These frequencies are the natural frequencies of the structure. By proper placement of the accelerometers, the mode shapes of the structure at its natural frequencies can also be determined, both for damaged or undamaged structures.

The high frequency response of the bridge will be determined by exciting the structures with modal hammers and instrumented drop weights. The modal hammers are capable of generating impulsive forces up to 5000 pounds and have usable frequency bands of 5 to 500 Hz. Drop weights instrumented with high-shock accelerometers can generate forces in excess of 10,000 pounds and useable frequencies down to nearly 1 Hz. Modal hammers and drop weights will probably not generate low enough frequencies to excite the fundamental modes, but they will excite higher modes. The advantage of using modal hammers and drop weights is that they are very portable and do not require installation on the structure like the eccentric mass shaker so testing can be performed very quickly and easily. This research will help determine if damage can be detected from the higher modes of the bridge structures.

The forced vibration analysis has real potential as a damage detection tool in situations where the extent of severe damage to a bridge (or a building) may not be readily discernible. There certainly will be cases where extreme damage to a bridge is very apparent and the need for reconstruction of the bridge is obvious. And conversely, there will be cases in which it is evident that a bridge has experienced very little damage from a collision, earthquake, or scour, etc. However, there will be many cases that lie in between these two extremes, where damage is obvious but the actual extent of the structural capacity lost is not known. A typical example of this could be where damage may be underground at the joint between a column and a pile cap or in newer ductile concrete frames where the joints may form a plastic hinge without collapse of the structure, but the true extent of the damage may not be readily visible.

In these cases the information that could be gathered through forced vibration analysis is the change in natural frequencies and mode shapes before and after damage. This can be directly related to a change in structural stiffness and load capacity. Experience with this technique is expected to lead to the ability to determine whether or not the structure can be repaired or must be reconstructed.

Identifying bridges that can be effectively repaired instead of having to be reconstructed potentially could offer tremendous cost savings, making the research well worth the investment.

In order to develop this technology, structures need to be subjected to forced vibration analysis both before and after controlled damage is induced. Of course, it is very rare to have full scale bridges available for controlled testing. Opportunities currently exist as part of the Interstate 15 reconstruction project through Salt Lake City, Utah. Phase One research considered a nine span bridge on northbound I-15 at South Temple Street scheduled for demolition. That work was pursued in conjunction with a number of cyclic push over tests to measure lost capacity due to corrosion as capacity gains through the use of carbon fiber composites. A research team at the University of Utah was under contract to perform the push over tests. These push over tests provided the damage necessary to cause changes in the structural condition of the bridge. The availability of this bridge provided the initial opportunity to investigate the potential of using forced vibration analysis and dynamic characterization as a non-destructive evaluation technique.

Phase 2 work, which is outlined in this work plan, is focused on extending the findings from the phase one research into the investigation of single bents, then to a multi-span structure, again with free-free boundary conditions (no abutment connections) and then on to a three-span structure which will be demolished and is therefore available for damage to be inflicted and results recorded. Phase three will involve the vibrating of some of the new bridges which have been built, including all of the bridges which are instrumented with strong motion instruments.

Using an eccentric mass shaker, the dynamic characteristics, natural frequencies, mode shapes, and modal damping ratios of the undamaged bridges will be determined. After the bridges have been damaged (controlled damage inflicted by the USU researchers) the dynamic characteristics will be determined again. The damage in the structure should be manifested in the change of the natural frequencies and mode shapes from the undamaged to the damaged state of the bridge. Should this change in dynamic characteristics be significant enough to note through forced vibration analysis, then this type of analysis could be used as a non-destructive evaluation technique to determine the magnitude and location of structural damage a bridge has suffered, due to whatever cause. This evaluation approach would be especially applicable to structures where damage might not be readily visible, for instance at the joint between a column and pile cap, or in newer ductile concrete structures where plastic hinges that form might not be immediately obvious or may be hidden by architectural coverings.

This work is promising and the opportunity to actually perform this work on full scale existing structures at various states of damage is rare and supported by researchers at the Federal Highway Administration (FHWA) and others.

RESEARCH GOALS/OBJECTIVES

The objective of this research is to investigate the potential for using forced vibration analysis and dynamic characterization of bridge structures as a non-destructive evaluation tool for the detection of structural damage and to assess the structural condition of these structures.

The tests planned at the 6^{th} South Bents, the 5^{th} South Viaduct, and the 3^{rd} North Bridge site will provide the opportunity to investigate the effectiveness of forced vibrationanalysis under many different bridge conditions, non-damaged, and a series of damage states at different locations on the bridge. This series of tests will provide a good indication of the potential for using forced vibration analysis as a non-destructive evaluation method and its possible limitations in damage detection.

The testing of the South Temple bridge was the successful phase I work within a multi-year research program investigating the use of forced vibration analysis as a non-destructive evaluation method.

POTENTIAL BENEFITS

Although modal analysis techniques have previously been used to study both model and full-scale structures (Liu and Yao, 1978; Aktan et al., 1995), the use of these techniques to evaluate possible damage in a full scale structure has not been well studied (Aktan et al., 1997). The work that has been performed has shown promising results and has further increased the interest in the technology. Particularly lacking is work on full-scale structures where testing has been performed on the structure in many states of damage. This is of great interest in order to determine if the various damage states can be characterized and identified. This level of global NDE would precede any local NDE technique to investigate the immediate level of damage that had been discovered and located using structural identification.

MAJOR WORK TASKS

The proposed research will consist of 12 separate tasks, each task focused on the dynamic testing of the bridges mentioned above. These tests will be conducted between February 1999 and February 2000.

The tasks planned as part of the dynamic analysis as a non-destructive evaluation (NDE) technique research are as outlined below. The schedule for these tasks is shown in the attached test schedule.

Task 1 - Equipment Preparation / Testing Protocal Plan

This task entails all the pre-testing preparation: inspection of the bridges to be tested, review of bridge design drawings, attending construction safety courses (required by UDOT), selecting the tests to be performed, preparing a test schedule, determining locations for instruments, checking instruments to verify that they are functioning properly, determining how to best store the data acquired during the tests, selecting equipment to be used (crane, manlift, scaffolding, etc.) on site, mobilization to the site and developing site security measures and developing a Testing Protocol Plan.

Task 2 - Site Preparation, 6th South Bent Caps and 5th South Viaduct

The use of a crane, manlift and a generator will be provided by Utah State University through equipment rental. All instrumentation will be located using surveying instruments, the Eccentric Mass Shaking Machine will be mounted using threaded rods and epoxy, and the full suite of instrumentation will be located at the site along with a generator and necessary lighting.

Task 3 - Forced Vibration and Modal Testing of Undamaged Bents from 6th South Viaduct

The individual bents left from the 6th South Viaduct will be fully instrumented and excited using both the eccentric mass shaker as well as the modal hammers to investigate the stiffness of these bents.

Task 4 - Forced Vibration and Modal Testing of Bents from 6th South Viaduct at Progressive Levels of Damage

The individual bents from the 6th South Viaduct will be damaged using a pneumatic hammer and a cutting torch in order to inflict damage at the beam column joints. Damage may also be inflicted at the interface between the columns and the pile caps. Testing as in task three will be repeated.

Task 5 - Testing of Undamaged Six Span 5th South Viaduct

a) As soon as the bridge is made available, Utah State University crews will mount the mass shaker and instruments onto the bridge and test the bridge as a complete structure.

b) The natural frequencies of the bridge will be determined up to 20 Hz using the eccentric mass shaker, whereas higher modes will be investigated using a series of drop weights and instrumented hammers.

Task 6 - Forced Vibration and Modal Testing of 5th South Viaduct at Progressive Levels of Damage

a) This six span bridge will then be damaged at one of the joints of one of the bents. The damage will be inflicted with a backhoe equipped with a pneumatic chisel to remove the concrete and a cutting torch to cut reinforcing bars.

b) Testing again will be conducted as in task five above.

c) Steps a) and b) above will be repeated up to ten times to systematically follow the degradation of this structure by using the vibration techniques as outlined in Muhammad, Halling, and Womack, 1999.

d) Each of these tests will be complete and extensive with complete frequency sweeps performed with each configuration of the instruments.

Task 7 - Data Analysis for 5th and 6th South Tests

During the five months after the field testing has been conducted the data collected from the tests will be analyzed. This data will be stored on 100 MB Zip disks in the field. Commercial software, MATLAB, will be used to analyze the data. Fast Fourier transforms can be programmed in MATLAB to determine natural frequencies of the structure and plot frequency-response curves. The damping of the structure will be determined from each forced vibration test using the Half-Power Bandwidth method. The mode shapes for each natural frequency of the bridge will be determined by comparing the relative responses of each accelerometer placed on the bridge. Intensive analysis of the flexibility of each member in the bridges will be compared to detailed models. SAP2000 and IDEAS will be utilized with a optimization routine to match the structural parameters of the model with the parameters frequencies, mode shapes and damping values determined experimentally. In this way the determination can be made as to whether the reduction in structural stiffness due to damage will be able to be detected and determined by optimizing the model to match the parameters.

Task 8 - Interim Findings and Results Report

After testing on the 5th South and 6th South structures is complete and after some of the data has been reduced and analyzed, a report is to be prepared which provides preliminary analysis and findings. From this report, the testing procedures for the 3rd North Structure may be modified based on lessons learned from previous tests and results. Additionally, an interim report will provide the Technical Advisory Team with a up to date progress and preliminary results.

Task 9 - Site Preparation of 3rd North Structure

The use of a crane, manlift and a generator will be provided by Utah State University through equipment rental. All instrumentation will be located using surveying instruments, the Eccentric Mass Shaking Machine will be mounted using threaded rods and epoxy, and the full suite of instrumentation will be located at the site along with a generator and necessary lighting.

This site is the next logical step in the progression of the research because it will involve applying these techniques to a Areal@ structure with actual boundary conditions at the two ends of the deck and will therefore be a sort of verification of the work explored in the more ideal structures presented in the earlier work.

Task 10 - Testing of the Undamaged Three Span 3rd North

a) As soon as the bridge is made available, Utah State University crews will mount the mass shaker and instruments onto the bridge and test the bridge as a complete structure.

b) The natural frequencies of the bridge will be determined up to 20 Hz and the mode shapes and modal damping values associated with these natural frequencies. In addition, the bridge will be excited using modal hammers to gain information on the higher frequency modes.

Task 11 - Testing of the 3rd North Structure at Progressive Levels of Damage

a) This three span bridge will then be damaged at one of the joints of one of the bents. The damage will be inflicted with a backhoe equipped with a pneumatic chisel to remove the concrete and a cutting torch to cut reinforcing bars.

b) The natural frequencies of the bridge will be determined up to 20 Hz and the mode shapes and modal damping values associated with these natural frequencies. In addition, the bridge will be excited using modal hammers to gain information on the higher frequency modes.

c) Steps a) and b) above will be repeated approximately three times to systematically follow the degradation of this structure by using the vibration techniques as outlined in Muhammad, Halling, and Womack, 1999.

d) Each of these tests will be complete and extensive with complete frequency sweeps performed with each configuration of the instruments.

Task 12 - Data Analysis for 3rd North Tests

During the three months after the field testing has been conducted the data collected from the tests will be analyzed. This data will be stored on 100 MB Zip disks in the field. Commercial software, MATLAB, will be used to analyze the data. Fast Fourier transforms can be programmed in MATLAB to determine natural frequencies of the structure and plot frequency-response curves. The damping of the structure will be determined from each forced vibration test using the Half-Power Bandwidth method. The mode shapes for each natural frequency of the bridge will be determined by comparing the relative responses of each accelerometer placed on the bridge. Intensive analysis of the flexibility of each member in the bridges will be compared to detailed models. SAP2000 and IDEAS will be utilized with a optimization routine to match the structural parameters of the model with the parameters frequencies, mode shapes and damping values determined experimentally. In this way the determination can be made as to whether the reduction in structural stiffness due to damage will be able to be detected and determined by optimizing the model to match the parameters.

Task 13 - Draft Technical Report Preparation

A Draft Technical Report is to be prepared and circulated to the Technical Advisory Committee for review and comments. Additionally, a presentation is to be made to the TAC after the report has been circulated. The Draft Technical Report is to contain preliminary recommendations on strategies to implement NDE using Forced-Vibration Technology on UDOT Structures.

Task 14 - Report Preparation

The last several months of the project award period will be utilized in finalizing the Final Technical Report and articles for journal publication and conference presentation. This material will be best disseminated through journal articles or conference presentations and proceedings.

INSTRUMENTATION / DATA COLLECTION AND EVALUATION

The instrumentation needed in this research will be 46 channels of forced balance accelerometers (Kinemetrics FBA-11), and very high precision velocity transducers which will be mounted in up to 96 different locations on each structure. These instruments are extremely robust, being sealed in water resistant cast iron boxes and have extremely high resolution. The accelerometers are the type used extensively in California and around the world for strong motion instrumentation at free field sites and in buildings and on bridges. Additionally, six Mark Products L-22E seismometers, Two 350B02 High Shock Accelerometers, and one Hewlett-Packard model 35670A four channel dynamic signal analyzer will be used. The excitation will be provided by an AFB Model 4600A Eccentric Mass Shaker and by two PCB modal hammers. Also a large mass drop hammer will be constructed to excite frequencies in the range of 20 to 100 hz.

Data will be collected by a National Instruments SCXI style acquisition system using LABVIEW software and using a 16 bit analog to digital card.

REPORTS/ MEETINGS/ PRESENTATIONS

Reports - Four (4) types of reports are expected as follows:

1. *Bi-monthly Progress Reports* are to be provided or when submitting for payment in accordance with Attachment B, Article B7- Progress and Progress Reports that describe:
   a) Progress and/or deliverables completed for the quarter
   b) Brief Synopsis of deliverable content
   c) Issues that have to be resolved

d) Work anticipated for next progress period.

2. Testing Protocol Plan

3. Interim Findings and Results Report:

4. *Technical Report* - A Final Technical Report is to be prepared that documents findings and results containing the necessary elements described in more detail in Attachment B, Article B9. A Draft Technical Report is to be circulated for review and comment with the UDOT Technical Advisory Committee. The Draft and Final Technical Report are to be delivered to the UDOT Project Manager for circulation according to the schedule shown in Section C3-Schedule.

5. *TRB Publication* – As a minimum, a technical paper summarizing the findings will be submitted to TRB for review and publication.

Meeting(s) - Approximately three (3) meetings are anticipated requiring travel to/from Salt Lake City for the research staff as follows:

	Group	Topic/Outcome
1.	Technical Advisory Committee	Confirmation of Testing Plan & Scope of Work
2.	Technical Advisory Committee	Review of Interim of Findings and Results
3.	Technical Advisory Committee	Review of Draft Technical Report

Presentation(s) - A final presentation & demonstration is expected and will be schedule at the review of the Draft Technical Report of the project and is to be given in Salt Lake City. The location and time of the meetings and final presentations will be determined in cooperation with the Research Project Manager and Principal Investigators. Also, presentations of the results will be given to AASHTO and TRB committees.

IMPLEMENTATION STRATEGY

The work described here is the second phase of a three phase project. Phase I included the study of the single span bridge at the South Temple location where the concept is proving to be very applicable and the results are promising. Phase III will include future work in monitoring the condition of new structures including a significant investment in the structures which will be instrumented permanently by the UDOT. To determine this, a before dynamic signature of these structures will be extremely valuable for monitoring the health of the structures through the years, as well as in the event of a major earthquake.

STAFFING AND SUBCONTRACTING PLAN

The principal investigator for this project will be Dr. Marvin Halling, working with Dr. Kevin Womack and Dr. James Bay as co-principal investigators. This team brings together a strong research group with varied interests. Dr. Halling has a strong background in earthquake engineering, geophysics, and vibrational testing of structures. His past research includes studies of the near source effects on base-isolated structures and includes considerable work in processing and analyzing strong motion data.

Dr. Womack has a strong background in structural dynamics and earthquake engineering.

Dr. Bay has many years experience in the characterization of the dynamic properties of materials, soils, and pavements. Dr. Bays field experience is extensive and his knowledge in instrumentation and data processing is a great asset to the research team.

The in-field experimental work will be conducted by Drs. Halling, Womack, and Bay, with assistance from Mr. Ken Jewkes, department technician/machinist, and several students from the civil engineering department at Utah State University. These students are: Ikhsan Muhammad (Ph.D. candidate), and several master students. The data analysis will be primarily conducted by Mr. Muhammad and the other master students under the supervision of the PI and Co-PIs.

The preparation of the Final Technical Reports, journal articles and presentations will be prepared by Drs. Halling, Womack, and Bay. This research will also result in three masters theses and a portion of a doctoral dissertation.

Subcontracting of work will be performed under this contract. This subcontracting will include the costs to the Penhall Company in order to facilitate the vibrational testing on the bridges as mentioned above.

Extensive coordination with UDOT, FHWA, Wasatch Constructors, The Penhall Company, and local business owners adjacent to the work will be a very high priority. This research will not be successful without a high level of cooperation and coordination.

SCHEDULE

The following schedule is anticipated under this contract. The duration and elapsed time shown for the testing may require modification as a result of the schedule changes of I-15 construction and related scheduling requirements. Close coordination between the UDOT research liaison and CONTRACTOR is necessary to exchange timely information regarding Wasatch Constructors and associated work.

Task	Project Schedule	Duration (in weeks)	Time Elapsed* (in weeks)
1	Equipment Preparation and Testing Protocol Plan	21.0 weeks	21.0
2	Site Preparation, 6th South Bent Caps & 5th South Viaduct	2.5 weeks	6.5
3	Testing - 6th South Bents, Undamaged	1.5 weeks	8.0
4	Testing - 6th South Bents, Progressive Levels of Damage	2.5 weeks	10.5
5	Testing - 5th South Viaduct, Undamaged	1.5 weeks	12.0
6	Testing - 5th South Viaduct, Progressive Levels of Damage	8.5 weeks	20.5
7	Data Analysis for 5th and 6th South Tests	20.5 weeks	41.0
8	Prepare Interim Findings and Results Report	4.5 weeks	25.0
9	Site Preparation- 3rd North	1.5 weeks	32.0
10	Testing - 3rd North, Undamaged	1.5 weeks	33.5
11	Testing - 3rd North, Damaged	1.5 weeks	35.0
12	Data Analysis for 3rd North	12 weeks	47.0
13	Prepare Draft Technical Report	11 weeks	52
14	Finalize Technical Report Prepare Journal Articles, AASHTO and TRB Presentations	4 weeks	56.0

* Project time line begins with the issuance of the ☐Notice To Proceed☐

BUDGET SUMMARY

USU Contract Costs:

Personnel Direct Costs:	$113,700
Equipment, Materials & Other Costs:	$ 92,300

Subtotal Contract Direct Costs, Equipment Etc. & Subcontracts:	*$206,000*
Indirect USU Contract Costs:	*$ 20,600*

Subtotal USU Contract Costs:	*$226,600*

UDOT Direct Costs:

Personnel Direct Costs:	$ 5,000
Equipment, Materials & Other Costs:	$ 8,000
Subcontracts:	$ 64,600

Subtotal UDOT Direct Costs, Equipment Etc. & Subcontracts:	*$ 77,600*

Total Project Costs:	***$304,200***

81F15026 – Existing Column / Beam Evaluation, Phase 1

Funding Source:	FHWA Research (TEA-21 FY 1999)		$ 40,960
	State Match (TEA-21 FY 1999)		$ 10,240
		*Total Cost Estimate	$ 51,200

Principal Investigator: Fernando Fonseca, Brigham Young University

Research Project Manager: Sam Sherman, UDOT

*Based on actual projected amounts for Research Division personnel and other costs. Matching amounts from other agencies are based on information provided by others and may not include all costs.

PROBLEM DEFINITION

Nearly one quarter million bridges in the United States are structurally deficient. Reinforcement corrosion and consequent concrete spalling are responsible for the deterioration of the majority of these structures. The bridges along the I-15 corridor, constructed in the early 1960's, are vivid examples of the deteriorated condition of our infrastructure system.

Corrosion of the reinforcing steel eventually makes the reinforcement useless. Concrete is a porous material that cracks when subjected to tensile stresses. Such a combination increases the probability of moisture penetration to the reinforcing steel. Deicing salts, which are generally mixtures of calcium and sodium chloride, are regularly used to treat bridge decks in Utah. The salt slowly propagates and eventually reaches the reinforcement. Ideal moisture content and critical salt concentration corrode the reinforcing steel which causes the steel to expand, creating forces that overcome the tensile capacity of the concrete. With failure of the concrete, the load transfer mechanism or bond between the reinforcing steel and concrete is broken and the reinforcement becomes essentially useless.

The prohibitive cost of replacing the large number of deteriorated, decaying, seismically deficient and seismically damaged structures increases the importance of developing methods to strengthen and/or retrofit existing structures. Advanced composite materials utilized by the aerospace industry world wide, have the potential, as demonstrated by CalTrans and others, to significantly extend the life of deteriorating steel reinforced concrete structures, while substantially upgrading their tolerance of seismic activity. This unique combination of technologies provides an unprecedented opportunity for increasing safety while decreasing life-cycle costs of existing and new highway bridge structures.

OBJECTIVES

The primary objectives of this study will be 1) to quantify the shear capacities of column-to-bent connections and bent haunches of existing deteriorated bridge structures, 2) to quantify the improvements in capacity of these sections which have been either retrofitted or strengthened using advanced composite materials, and 3) to develop finite element models capable of representing the response of column-to-bent connections and bent haunches.

These objectives will be accomplished by testing four bents in the structural laboratory at Brigham Young University.

POTENTIAL BENEFITS

The measured and calculated responses of the systems tested will become bench marks to any predictions of load capacities of similar systems. The opportunity to test both column-to-bent connections and bent haunches of existing deteriorated bridges structures will provide valuable information on the actual load capacities of these elements. The empirical results combined with the developed finite element models could be used by practicing structural engineers to calculate load capacities of steel reinforced concrete bridges of similar conditions across the country.

The development of proven methods to strengthen and retrofit column-to-bent connections and bent haunches with advanced composite wraps would add confidence in the use of this technique and lead to improved designs in future applications.

Further, engineers can use the results of the testing program and the validated finite element models when determining whether or not deteriorated structures actually need to be repaired, what the extent of the repair should be and what type of repair will be most effective.

MAJOR WORK TASKS

This study has been divided into two phases that are scheduled over two years. Phase I is limited to the collection of field specimens, which must be completed in accordance with the schedule of the D/B Reconstruction Project. The only task to be completed in the field is the removal and transportation of the bents. This would avoid further delaying or interfering with the activities of the demolition contractor since removal of the bents will be required anyway. Removal and transportation will be accomplished without further damaging the already deteriorated structural elements. Phase II will include the laboratory testing of both as-is as well as retrofitted specimens.

Note that only funding for Phase I of the study is included in this specific research program. Other funding sources will be sought to complete Phases II. However, the work tasks for Phase II have been shown for completeness.

The following specific tasks will be pursued:

1. Select the bents to be tested;
2. Cut the selected bents. Two cuts will be required □ one per column. A crane will be used to support the bents to take the weight off of the cut during cutting;
3. Transport the bents to the structural laboratory at Brigham Young University. The elements will be carefully placed on trailers for transportation to BYU;
4. Set up loading and reaction frames. The structural laboratory will be used during testing of the bents;
5. Set up instrumentation and data acquisition system; and,
6. Conduct the tests.

Finite element models will be developed concurrently with the testing program. The measured response will be used to validate and refine the models.

Each bent will provide two cantilevered end haunches (Shear Haunch tests) and two column-to-bent connections (Shear Joint tests). Tests will be conducted in an AS IS and RETROFITTED/STRENGTHENED (RETRO) conditions to evaluate the deteriorated and the retrofitted/strengthened capacities of the bridge structures, respectively. Bent No. 1 will be tested to failure and will serve as a bench mark. Bent No. 2 will be tested to its yield capacity and then retrofitted using conventional wrapping. This test will represent the conditions of a pre-damaged specimen and the benefits of a retrofitting scheme. Bent No. 3 will be strengthened using the same retrofitting technique used for Bent No. 2. Tests conducted on Bent No. 3 will quantify the improvements in capacity due to different strengthening schemes.

BENT No.	TEST No.	SHEAR□HAUNCH TESTS	
		AS IS	RETRO
1	1a	Tested to Failure	No
	1b		
2	2a	Tested to Yield	Yes
	2b		
3	3a	No	Yes
	3b		

INSTRUMENTATION/DATA COLLECTION AND EVALUATION

The engineering building at BYU houses a complete structural laboratory. The laboratory has a clear height of about 30 feet and is fully equipped with servo-hydraulic test equipment, reaction frames, and a strong floor. Existing computers are dedicated to data acquisition.

The response of the specimens will be monitored during the tests with Linear Variable Differential Transformer (LVDT) transducers and strain gages. The instruments will be located throughout the test structures in an arrangement such that data can be collected in order to validate and refine the finite element model. A displacement control algorithm will be used in order to minimize the possibility of catastrophic failure of the specimens.

The measured responses of the bench mark specimens will be compared to original design capacities as determined from available as-built drawings of the specimens tested. This comparison will allow the accomplishment of the first objective of this research which is to quantify the shear capacities of column-to-bent connections and bent haunches of existing deteriorated bridges structures. Also, it will indicate the effect of deterioration on load capacities.

The measured responses of the various retrofitted and strengthened specimens will be compared to the response of the bench mark specimens. This comparison will quantify the improvements in capacity of the sections that have been either retrofitted or strengthened using advanced composite materials. This will effectively accomplish the second objective of this research.

The measured response will then be used to validate and refine the developed finite element models, accomplishing the third and last objective of this research.

REPORTS AND PRESENTATIONS

A final report containing detailed information about the specimens, testing procedure and measured responses will be produced. The procedure used to develop the finite element models as well as calculated responses will also be included in the final report.

In addition, conference presentations will be sought and archive journal publications will be submitted to transfer technology advanced in this study to other researchers.

STAFFING AND SUBCONTRACTING PLAN

This project will be under the direction of Dr. Fernando S. Fonseca, an Assistant Professor at BYU. Dr. David W. Jensen, an Associate Professor at BYU will serve as Co-Principal Investigator. Graduate students will be employed as needed to accomplish the stated research objectives. The field portion of the study must be closely coordinated with Penhall Company, the demolition subcontractor for the D/B Reconstruction Project.

SCHEDULE

Due to budgetary constraints, two years will be necessary to accomplish both phases of the proposed research. In the first year, the bents will be cut and transported to BYU. In the second year, the testing and development of the finite element models will take place. The timing for Phase I will be the summer of 1999 and shall be coordinated with the schedule of the D/B Reconstruction Project.

BUDGET SUMMARY (Phase I)

BYU Contract Costs:	
Equipment, Materials & Other Costs:	$ 7,272
Subtotal Contract Direct Costs, Equipment Etc. & Subcontracts:	*$ 7,272*
Indirect BYU Contract Costs:	*$ 728*
Subtotal BYU Contract Costs:	*$ 8,000*
UDOT Direct Costs:	
Personnel Direct Costs:	$ 700
Equipment, Materials & Other Costs:	$ 500
Subcontracts:	$ 42,000
Subtotal UDOT Direct Costs, Equipment Etc. & Subcontracts:	*$ 43,200*
Total Project Costs:	***$ 51,200***